ECONOMIC GEOLOGY

Vol. XX. MAY, 1925. No. 3.

THE SO-CALLED "PSEUDOMORPHOUS" QUARTZ OF TERTIARY GOLD-SILVER VEINS.

P. G. MORGAN.

PLATY, lamellar, or tabular quartz is found in many mineral lodes, more especially those traversing volcanic rocks of Tertiary age. The plates are of all sizes up to many square inches, and commonly intersect or meet at angles suggesting on casual examination the rhombohedra of calcite (Fig. 1). They are usu-

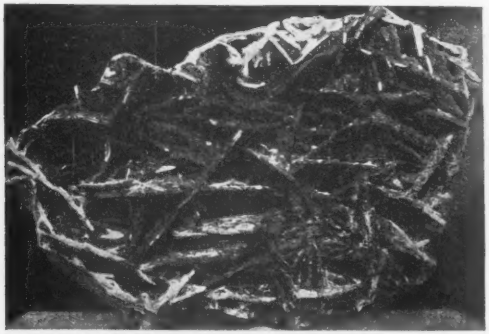


FIG. 1. Lamellar or Platy Quartz, Waihi Mine, New Zealand. Back of specimen shows semi-platy quartz but is not cavernous. (Size of Specimen 18 in. x 12 in.)

ally explained as pseudomorphs of that mineral, and important deductions have been made on this assumption. The object of

this paper, however, is to show that platy quartz as found in mineral lodes or elsewhere is no more pseudomorphous after calcite or other minerals than the quartz of graphic granite is pseudomorphous after the feldspar with which it is intergrown. The term "pseudomorph," and its derivatives are here understood to be restricted to cases in which one mineral has actually replaced another, and not to apply to the moulding of one mineral upon another, such as happens in intergrowths. The so-called pseudomorphs by incrustation, where there has been no substitution of one mineral for another, for the sake of clearness ought also to be excluded from the class of pseudomorphs.

In New Zealand quartz supposed to be pseudomorphous after calcite was observed by Julius von Haast in 1866 or earlier. The first record of lamellar quartz in a mining district was made by Cox,[1] who in 1883 noticed in the Martha lode, Waihi, a "curious" type of quartz, which appeared to "form pseudomorphous crystals after some other mineral." In 1892 McKay[2] described platy quartz as occurring in the silver-bearing lodes of the Puhipuhi district, North Auckland.

In 1899 Lindgren noted the occurrence of lamellar "pseudomorphous" quartz in the lodes of the De Lamar district, Idaho. He remarks: "It seems most probable that calcite was the original mineral of these pseudomorphs, though barite may also have been present. The thin plates of quartz may originally have been deposited between the calcite grains. When the latter were dissolved the quartz remained, and the cells were filled or coated with secondary quartz."[3] The explanation given is rather puzzling, seeing that the plates themselves are regarded as pseudomorphous. During the past twenty-five years lamellar quartz has been recorded from many other mining districts. Generally it is unhesitatingly regarded as pseudomorphous after calcite.

[1] S. H. Cox, "Goldfields of the Cape Colville Peninsula," *Rep. Geol. Explor. during 1882*, No. 15, pp. 4–51, 1883. See p. 37.

[2] A. McKay, "On the Puhipuhi Silverfield, Auckland," *Rep Geol. Explor. during 1890–91*, No. 21, pp. 55–59, 1892. See p. 57.

[3] Waldemar Lindgren, "The Gold and Silver Veins of Silver City, De Lamar and other Mining Districts in Idaho," Twentieth Ann. Rep. U. S. Geol. Surv., vol. 3, pp. 65–256, 1899. See p. 170, also pp. 139, 159, 164–165, etc., and plates 28, 30.

Lindgren's later statements [4] concerning lamellar quartz are not so clear as could be wished. In 1905 he describes the lamellar quartz of the Waihi Mine as originally an intimate intergrowth of quartz and calcite from which the calcite has commonly been dissolved, in whole or in part, and there need be no dissent from this. In 1913 he implies that all lamellar quartz of the nature under discussion is "pseudomorphic" or secondary, and states that its formation has nothing to do with surface waters.

W. H. Emmons [5] applies the term negative pseudomorphs to the cavities formed by the solution of calcite from a quartz-calcite vein-stone, and thus explains the genesis of "imbricating blades of quartz which join at angles that represent the cleavage of calcite." In the present writer's experience, however, the angles rarely approach closely to the cleavage of calcite.

The established nature of the concept that lamellar quartz is pseudomorphic is illustrated in recent bulletins of the United States Geological Survey written by Shrader [6] and Ransome.[7] Since the plates of quartz are commonly coated by small quartz crystals, plainly secondary (though not pseudomorphous), the presence of a little truly pseudomorphic quartz is possible. Where, however, as in the lower levels of those mines where platy quartz is found, calcite has not been dissolved, the quartz of the solid quartz-calcite intergrowth is wholly primary.

Since quartz and calcite both belong to the rhombohedral division of the hexagonal system, their ability to form the remarkable intergrowths revealed by the removal of the calcite in solution can be readily understood. As seen in graphic granite, the intergrowth of quartz and feldspar, which belong to different crystallographic systems, is often developed to a wonderful ex-

[4] Waldemar Lindgren, "The Hauraki Goldfields, New Zealand," *Eng. and Min. Jour.*, vol. 79, pp. 218–221, Feb. 2, 1905; "The Annie Laurie Mine, Piute County, Utah," U. S. Geol. Surv. Bull. 285, pp. 87–90, 1905 (see p. 89); "Mineral Deposits," 2d impression, pp. 156, 436–439, 1913; etc.

[5] W. H. Emmons, "The Enrichment of Ore Deposits," U. S. Geol. Surv. Bull. 625, p. 72, 1917.

[6] F. C. Shrader, "The Jarbridge Mining District, Nevada," U. S. Geol. Surv. Bull. 741, 1923.

[7] F. L. Ransome, "Geology of the Oatman Gold District, Arizona," U. S. Geol. Surv. Bull. 743, 1923.

tent. In many cases two or more metallic minerals are intergrown in such a way that their time relations are uncertain, and what seem primary minerals to one worker may seem secondary to another.

Recently the writer has examined in great detail the veinstone of the Waihi mines, Hauraki Goldfield, New Zealand. Thin sections made from the veinlets which occur in the quartz andesites enclosing the lodes, and were of contemporaneous formation with the lodes, like them have quartz, calcite, and adularia (var. valencianite) as their principal mineral constituents. The relations of the three minerals are clearly shown in the sections. Valencianite was usually the first to begin to form: then quartz and calcite appear, the quartz having a tendency to precede the calcite. In the larger veins or lodes quartz and valencianite are contemporaneous; quartz and calcite are also practically contemporaneous. In many cases the quartz in part slightly precedes the calcite. Sections made of highly calcitic veinstone show patches of quartz mosaic moulded on the calcite, in this case slightly " earlier " than the quartz, which has had to content itself with whatever spaces it could find between the growing crystals of calcite. Elsewhere the chief evidence of calcite preceding quartz is that the calcite cleavage in some specimens is impressed on the plates of quartz, but it does not penetrate these, and therefore there is no evidence of replacement. The cleavage markings are presumably caused by the mode in which intergrowth takes place.

" Sugary " quartz, or quartz in small loose crystals and fragments, is common in the lodes of the Waihi and adjoining districts. This has been explained as formed by the crushing of quartz, but it really represents a fine-grained intimate intergrowth of quartz and calcite, from which the latter mineral has been removed in solution. It is found only in the zones of oxidation.

The presence of lamellar quartz in a vein has been interpreted as conclusive evidence of two periods of vein formation by ascending solutions. In the earlier of these, calcite, either alone, or with subordinate amounts of other minerals, is supposed to have been deposited in the veins; in the later, quartz replaces part

of the calcite, and the remaining calcite may also be removed in solution. This view was advanced by J. M. Bell and C. Fraser in their description of the lodes of the Waihi and adjoining districts. If, however, the data are interpreted as here suggested one sees, not only that the quartz is primary, but that there was only one period of mineralization by ascending waters. Where cavernous quartz, such as that of Fig. 1, is found, descending waters have played a part. The true interpretation of lamellar quartz is therefore a matter of great importance. Its occurrence in lodes tends to disprove the present fashionable view that there has been more than one period of vein-filling by ascending waters in the metalliferous lodes of "Tertiary" goldfields.

BIBLIOGRAPHY.

The following references to publications in which there appear illustrations of lamellar quartz or quartz-calcite associations may be useful:

WALDEMAR LINDGREN: The Gold and Silver Veins of Silver City, De Lamar and other Mining Districts in Idaho. Twentieth Ann. Rep. U. S. Geol. Surv., vol. 3, pp. 65–256, 1899. See Plates 28 and 30.

WALDEMAR LINDGREN: Mineral Deposits, McGraw Hill Co., 1st edition, 2d impression, 1913. See Figs. 132–134.

CHARLES W. GOODALE: The Drumlumnon Mine, Marysville, Mont. *Trans. Amer. Inst. Min. Eng.*, vol. 49, pp. 258–283, 1915. See Fig. 9.

M. H. CARON: Het Zilver-goudertsvoorkomen van Ager Gedang Ilir, Afdeeling Lebong der Residentie Bengkoelen, Sumatra. *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië, 1915*, Tweede Gedeelte, pp. 55–69, 1917. See Figs. 2–7. Figs. 2, 3, 4, and 7 represent typical lamellar quartz.

SIDNEY F. ADAMS: A Microscopic Study of Vein Quartz. ECON. GEOL., vol. 15, No. 8, pp. 623–664, 1920. See Plate 25, *E*, *F*; and Plate 26, *A*.

FRANK C. SHRADER: The Jarbridge Mining District, Nevada. U. S. Geol. Surv. Bull. 741, 1923. See Plates 10, 12, and 15.

F. L. RANSOME: Geology of the Oatman Gold District, Arizona. U. S. Geol. Surv. Bull. 743, 1917. See Figs. 4 and 5, the former of which is stated to represent residual calcite and replacing quartz, the latter a lamellar aggregate of quartz, calcite, and adularia.

A. LACROIX: Minéralogie de Madagascar. Tome 1, Plate 4, Fig. 7, 1922. See also pp. 204, 282.

P. G. MORGAN: The Geology and Mines of the Waihi District, Hauraki Goldfield, New Zealand. N. Z. Geol. Surv. Bull. No. 26, Plates 1 and 2, 1924. See also Plates V., Figs. 1, 2; VI., Fig. 3, and p. 87.

WELLINGTON,
NEW ZEALAND.

MAY

GRAPHITE DEPOSITS OF ASHLAND, ALABAMA.[1]

JOHN S. BROWN.

CONTENTS.

Introduction 208
Surface features 210
Geological setting 210
Subdivisions of the Ashland series 213
Metamorphic rocks 213
Non-graphitic garnetiferous schist or gneiss 213
Hornblende schist or gneiss 214
Graphitic schist series 219
Intrusive rocks 222
General features 222
Intrusives of the graphitic area 223
Structure 225
Geology of the Ceylon mine, Coosa County 228
Age of the Ashland series 229
Original nature of the metamorphic rocks 230
Graphite 233
Tenor of ores 236
Petrography of the graphitic rocks 236
Massive graphite and graphite veins 244
Graphite in Talladega slate 244
Origin of the graphite 245
Troublesome impurities in the flake 246
Practical applications of the study 247

INTRODUCTION.

ALL the graphite deposits of Alabama are situated in the eastern central part of the state in the triangular area of metamorphic rocks that forms the termination of the well-known Piedmont belt.[2] Two areas, the more important one entirely in Clay

[1] Society of Economic Geologists, New York Meeting, May, 1924. Prepared through the award of the Emmons Memorial Fellowship.

[2] For location of these areas see Index Maps by Prouty, W. F., "Geology and Mineral Resources of Clay County," County Rep. No. 1, Geol. Surv. of Alabama, 1923, pp. 13, 98.

County, the other chiefly in Coosa but partly in Chilton County, contain all the deposits of probable commercial importance. This paper deals mainly with a part of the Clay County area west of Ashland, in the heart of the producing territory.

The occurrence of graphite in this area has long been known, and mining was attempted in 1888, but was only established successfully in a small way about 1900. Production gradually increased until about 1913 Alabama became, and has still remained, the leading graphite-producing state. War demands, combined with a reduction of imports from Madagascar and Ceylon, induced enormous, and ultimately disastrous, expansion in the domestic industry between 1916 and 1919. More than 40 mines were established in Clay County, most of them now dismantled and in ruins. The openings that were made, however, are still accessible, and are of much assistance in the study of this region where deep weathering commonly obscures so much of the geological detail.

Briefly stated, the graphite in Alabama impregnates crystalline schists which usually dip steeply to the southeast. Virtually all the mining has been open cut work seldom carried below the oxidized zone, since the unweathered ore is harder and much more refractory. The ore is low grade, averaging 2 to 3 per cent. graphite, and must be concentrated before shipment, various methods being employed for the purpose. Production in 1918 reached nearly 8,000,000 pounds with a value of almost 1,000,000 dollars. The best existing account of the history and geology of the deposits is by Prouty.[3] Dub and Moses[4] give many valuable details regarding mining and milling.

Acknowledgments.—In 1922 the writer was awarded the Emmons Memorial Fellowship in Geology which enabled him to undertake a study of some of the graphite deposits in Alabama, where two months were spent in 1922. In 1923 short trips were made to various noted deposits in Pennsylvania, New

[3] Prouty, W. F., "Geology and Mineral Resources of Clay County," County Report No. 1, Geol. Survey of Alabama, 1923.

[4] Dub, G. G., and Moses, F. G., "Mining and Preparing Domestic Graphite for Crucible Use," U. S. Bureau of Mines, Bulletin 112, 1920.

Jersey and Massachusetts. This paper, however, deals only with the Alabama deposits.

To Professor James F. Kemp, of Columbia University, who, during several pleasant days in Alabama, contributed from the fund of his long experience in the geology of igneous and metamorphic rocks, and who has since maintained a friendly interest in this work, the writer is particularly indebted. The assistance and hospitality of Mr. J. C. Barton, General Manager of the Griesemer Graphite Company, also contributed immeasurably to the success of the work. Professors Charles P. Berkey and Roy J. Colony, of Columbia, have kindly supervised the microscopic studies.

Professors C. L. Dake and Josiah Bridge, of the Missouri School of Mines, have also assisted, the one in criticisms of the manuscript, the other in preparing the photomicrographs.

SURFACE FEATURES.

That part of the Piedmont belt in which the graphite deposits are situated is a moderately dissected upland which is generally supposed to have been at one time a peneplain. The upland around Ashland is from 1000 to 1100 feet above sea level, but the main ridges rise 200 to 300 feet higher giving a local relief of 300 to 400 feet. The graphitic area is rather rugged and is characterized by numerous ridges of northeasterly trend whose direction and relief are controlled by the structure and hardness of the rocks. Since the schists usually dip southeast, ridges often are asymmetric and steepened on the northwest.

GEOLOGICAL SETTING.

A variety of metamorphic rocks, schist, gneiss and marble, together with some large bodies of nearly unmodified granitoid intrusives constitute the bulk of Piedmont rocks in Alabama.[5] In general, the intrusives occur in long, narrow belts, trending roughly northeasterly. The same or similar rocks frequently

[5] For description of these rocks as a whole, see the various publications of the Geological Survey of Alabama, especially Bulletin No. 5, Mineral Resources of the Upper Gold Belt, etc., 1896.

constitute different belts, presumably because of folding, or of faulting parallel to the strike.

The rocks of Clay County are described best by Prouty.[6] Workable deposits of graphite are restricted wholly to a part of what he has mapped and described as the Ashland series, the oldest rocks of the region, supposedly pre-Cambrian. This series includes various types of crystalline schist and occupies mainly a belt 10 or 12 miles wide extending from the northeast corner southwestward through the middle of Clay County, terminating abruptly 8 or 9 miles southwest of Ashland.

A very narrow band of Hillabee schist, supposed to be an altered basic intrusive, borders the Ashland on the northwest, and forms a considerably broader area on the southwest where the Ashland terminates. The Hillabee separates the Ashland from a broad belt of Talladega slate, typically a semi-crystalline, blue-gray slate or argillite. This is a part of what is often referred to as the Ocoee of Georgia and Alabama, of which some portion is known to be Cambrian. A part of the Talladega in Clay County is Carboniferous as proved by fossil plants.[7] The Talladega is of interest here because in places it contains a large amount of amorphous graphite.

Southeast of the Ashland series is a strip or number of narrow strips of granitoid rocks, called locally by Prouty[8] the Bluff Springs granite, considered by him to be the equivalent of the Pinckneyville granite which occupies a much larger area to the southwest, chiefly in Tallapoosa County. The Bluff Springs granite separates the Ashland series from a second broad belt of Talladega. Both the Ashland and the Talladega have been so altered at the contact with the Bluff Springs granite by its intrusive effects that Prouty has mapped a part of them as Altered Ashland and Altered Talladega respectively.

[6] *Op. cit.*

[7] Smith, E. A., "Carboniferous Fossils in 'Ocoee' Slates in Alabama," *Science,* new ser., XVIII., pp. 244–246, 1903. Prouty, W. F., "Age of Talladega Slates of Alabama," *Pan-American Geologist,* XXXVII., pp. 363–366, 1922.

[8] "Geology and Mineral Resources of Clay County," Ala. Geological Survey, 1923.

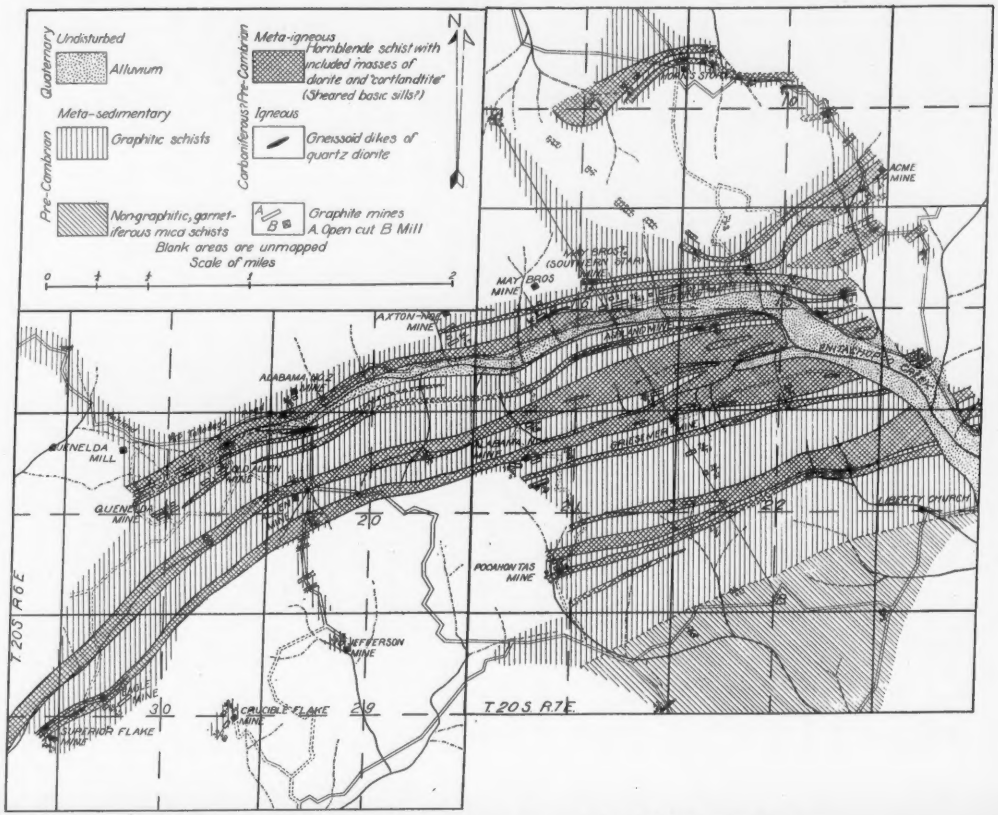


FIG. 1. Detailed geological map of a part of the Ashland graphite area.

In summary the Ashland area is a broad belt of fully crystalline Ashland schists bordered on either side by narrow bands of igneous rock and beyond that on either side by the semi-crystalline Talladega slates. The structural relations are given by Prouty [9] in a structure section across the central part of Clay County.

The Ashland series, as its name indicates, is not a unit but a group of related rocks. Most of the different types are mentioned by Prouty [10] but he did not attempt to map them although he has separated them in some of his sections.[11]

The rest of this description is based on the writer's personal study, and refers to the units represented on the geological map, Fig. 1.

FIG. 1. Detailed geological map of a part of the Ashland graphite area.

ASHLAND SERIES—METAMORPHIC ROCKS.

Non-graphitic Garnetiferous Schist or Gneiss.

A garnetiferous biotite schist or gneiss, apparently the "Altered Ashland" of Prouty, borders the graphitic area on the southeast. Excessive injection by pegmatite and vein quartz is one of its prominent features. Pegmatites several feet thick are fairly common but much of the vein matter is in streaks less than an inch thick parallel to the schistosity, thus giving the rock a gneissic banding. The amount and thickness of pegmatitic matter seems to increase to the southeast. Pegmatites often carry pockets of coarse mica flakes ½ inch to 1 inch in diameter which may remain as conspicuous residual fragments.

The minerals visible in hand specimens include quartz, gray or white feldspar, small reddish garnets, and abundant black biotite. Graphite may appear in traces. Thin sections show that the feldspar is basic plagioclase, and usually exceeds in amount the quartz, some of which often occupies distinctly injected bands. The garnets are probably almandite, and occur as metacrysts clearly later than the dominant minerals, having formed apparently at the expense of quartz, feldspar and mica, of which they

[9] *Loc. cit.*, See accompanying geological map of Clay County (Fig. 1).
[10] *Op. cit.* See pp. 16–21.
[11] *Op. cit.* See pp. 98–108.

contain inclusions. Sillimanite and magnetite are common accessories.

As a rule the rock is deeply weathered. The soil is a reddish clay and the subsoil is typically red with prominent variegated spots due to particles of white kaolin and of black manganese oxide, the latter probably derived from the garnet or the biotite.

Prouty maps the contact of this rock with the graphitic Ashland as a fault, which it may well be, although to the writer it seemed rather that the contact is gradational over a zone about ½ mile wide.

Hornblende Schist or Gneiss.

This formation consists essentially of totally non-graphitic hornblende schist, with local lenses of very peculiar related types. These rocks have never been discriminated carefully in any of the Alabama Survey's reports, as they are the least extensive and most deeply weathered formation. Natural exposures are rare and poor and consist usually of the least typical material. Nevertheless, once the key to their identification is obtained, the hornblende schists are the easiest formation in the area to map and they are of great importance in separating and correlating the different bands of the graphitic series and in affording a clue to the structure of the region. The map represents them quite accurately except in a few places where the structure is unusually complex or where a prohibitive cover of soil or alluvium is present.

A. Hornblende Schist.—This is the predominant type. Fresh hand specimens are dense, fine-grained, black and white or speckled schists with excellent cleavage. The black mineral is hornblende, the white feldspar, but the grains usually are so small they can hardly be positively distinguished even with a hand lens. The feldspar frequently forms narrow white bands a millimeter or two in thickness giving the rock a gneissic appearance. Weathered outcrops commonly split into many thin layers 1 or 2 inches thick which yield flat, elongated float fragments. These are invariably deeply weathered and covered with a brown

or yellow earthy crust. One can usually find specks of hornblende in the center, however.

In thin section fresh specimens usually consist of 80 to 90 per cent. hornblende and plagioclase in about equal amounts. The hornblende is pale green to clear and faintly pleochroic. Part of it seems to be pargasite. The plagioclase is usually as basic as labradorite but varies between andesine and anorthite, being constant in individual sections. Fractures in the grains filled by needle-like patches of alteration products are common, as are also white kaolinic patches, and sericite. Saussurite was noted in hydrothermally altered specimens.

Pyroxene if present is always a clear, magnesian variety. In some sections it reaches 10 per cent. From 1 to 2 per cent. of titanite is an invariable constituent. Small brown grains usually sheared and strung out in lenses, are characteristic. Magnetite often accompanies titanite. Zoisite occurs as an alteration product and probably also as an original constituent.

Soil and topographic features are of great assistance in mapping the hornblende schist in the field. The soil is always red, and the subsoil a deep, even-textured red, yielding a sticky clay when wet. Beneath the subsoil in the numerous gullies which trench it one often finds a red and black or yellow and black, punk-like, micaceous mass showing a banded structure inherited from the weathered schist, the fresh phase of which occurs at greater depth. Float fragments of the peculiar related types described later are also characteristic. The hornblende schists are the least resistant to erosion of all the rocks in the region, and this fact is characteristically expressed in the topography. The broader bands of hornblende schist generally occupy prominent northeast-southwest strike valleys. The narrower bands outcropping on slopes between the graphitic schists usually occupy peculiar saddle-shaped depressions where they cross ridges that lead down to the main valleys.

The hornblende schists appear to have resisted to a great extent those injecting influences so evident in the associated schists. It is true that veins of quartz and pegmatite are found in them,

but they appear to be chiefly those of larger size and presumably greater intrusive force. There is no evidence in the hornblende schists, particularly in thin sections, of that intimately injected nature that characterizes the micaceous and graphitic schists.

B. Hornblende Diorite.—A striking dioritic rock, massive, or with a slight gneissic banding, occurs as definite lenses within the fine-grained hornblende schist. Hand specimens consist of a more or less equal mixture of stubby black hornblende crystals in a matrix of fine-grained white feldspar. In thin section the hornblende and the feldspar appear to be identical with that of the fine-grained hornblende schist, and the accessories are apparently the same. There appear to be all gradations in size of grain from the coarse massive diorite to the ordinary fine-grained schist.

Several exposures were found which proved conclusively the true interfoliated and lenticular nature of this rock.

Commonly, however, the only indication of its presence is the occurrence of loose, weathered blocks, some of which may be 2 or 3 feet in diameter. These may even form ledges that can be traced several hundred feet along the strike. Very often the diorite is closely associated with the peculiar "Cortlandtite" described as type *C*.

C. "Cortlandtite."—From neighboring parts of Alabama, Clements [12] has described thin sections of rocks apparently identical with this type and has noted their close resemblance to the "Cortlandtite" of the Hudson Valley, New York, originally described and named by Williams.[13] Fresh hand specimens may be strictly massive or may show a faint gneissic structure as if they had been crushed. They are dark green, almost black in color, quite fine-grained and exceedingly uniform in texture, and unusually heavy. Thin sections show that the predominant mineral is hornblende, pale green and faintly pleochroic. A part of it often appears to be pargasite. The grains are small, uniform

[12] Clements, J. M., in Bull. No. 5, Geol. Surv. of Alabama, "Mineral Resources of the Upper Gold Belt," pp. 156–159, 1896.

[13] Williams, G. H., "Peridotites of the 'Cortlandt Series' on the Hudson River near Peekskill, N. Y.," *Am. Jour. Sci.*, III., vol. 31, pp. 26–40, 1886; see p. 30.

in size, and sometimes show an imperfect parallel orientation. Usually hornblende constitutes 50 per cent., often 75 per cent. of the rock.

The next most abundant mineral commonly is a clear or faintly pleochroic and purplish pyroxene, apparently enstatite, in much larger and strongly poikilitic crystals, often 1 or 2 millimeters in diameter. Small amounts of a clear monoclinic magnesian pyroxene in much smaller grains are often present.

Typical accessories, seemingly present in all sections, are magnetite and a rich, deep green spinel (pleonaste). The magnetite may show crystal form but the spinel is always in irregular grains usually in niches between the other minerals. Spinel and magnetite together rarely comprise 10 per cent. of the rock, but they are more typical than other accessories that occasionally exceed them in abundance.

A trace of olivine is present in some sections and in one it constitutes more than 10 per cent. of the rock. It is a clear magnesian variety, optically negative and seems to be altering to an iron-stained serpentine.

Both biotite and muscovite were noted in different sections and a trace of something resembling talc as an alteration product in another.

This "cortlandtite" seems to bear a relation to the hornblende schists similar to that of the hornblende diorite with which it is often but not necessarily associated. It is scarcely ever found except as loose residual blocks or heaps of rounded boulders often several feet in diameter. The boulders are generally black or greenish in color, often with a brownish, iridescent tarnish. Their surfaces are often wavy or irregularly pitted in detail. A brown alteration border may extend inward about ¼ inch, rarely an inch or more. The alteration product is a tough, chloritic mass.

One of the largest outcrops of these boulders, caps a conical hill (Center NW. ¼ SW. ¼ Sec. 15, T. 20 S., R. 7 E.) and another is found about ¼ mile southwest of this, forming a ridge on an intermediate slope. At both these places the patches are elon-

gated along the strike, and in each case the "cortlandtite" boulders diminish in number and size to the northeast and are gradually replaced by boulders of hornblende diorite.

No good excavations showing the rock *in situ* could be found but small exposures at 3 places in road cuts indicate that it is intercalated in the hornblende schist in somewhat the same manner as the hornblende diorite.

Weathered fragments of both the hornblende diorite and the "cortlandtite," because of their unusual lithologic character and limited distribution, are valuable markers, where present, in tracing the outcrops of the enclosing hornblende schists, with which they seem invariably to be associated.

Occurrence of Hornblende Schists.—Contacts between the hornblende schists and the graphitic schists usually are quite sharp, although at times a gradation interval of a foot or two may be found. More often if there is a gradation it is accomplished by intercalation, thin bands of graphitic schist appearing in the hornblende schist and increasing in number and thickness until the latter disappears, usually within a few feet. Lenses of graphitic schist seem to occur even in the middle of some of the hornblende schists. It is generally impossible to map them and it is probable they are a good deal more common than might be suspected, as only occasional good exposures prove their existence.

Surface outcrops of the hornblende schists thin and thicken considerably. Occasionally they seem to pinch out entirely and occasionally they appear to coalesce. Nevertheless even the thinner bands are remarkably persistent. They evidently were originally interbedded units in a sedimentary series though probably not of sedimentary origin. They seem to correspond in extent with the graphitic belt, and are closely associated with the graphite deposits throughout the area shown in Fig. 1. Similar hornblende schists are found in the graphitic part of the section along the Atlanta, Birmingham and Atlantic railroad between Pyriton and Lineville, and according to Prouty's description appear to extend at least as far as his area of "basic rock" in the

northeast corner of the county, with which they probably are identical. Seemingly identical hornblende schists are also found associated with the graphitic schists at the Ceylon mine in Coosa County.

Graphitic Schist Series.

With the graphitic schist is included on the map a large mass of schists containing little or no graphite and of rather different lithological composition. The different types are so intercalated, so deeply weathered, and so poorly exposed that it is impossible to differentiate them closely except in occasional favorable sections. More than 90 per cent. of the series can be grouped under two main heads: (*A*) garnetiferous mica schist containing little or no graphite, (*B*) extremely siliceous mica schist carrying considerable graphite, locally rich enough to be of possible commercial value. In type (*A*) the mica is characteristically biotite, and in type (*B*) muscovite, but the variations are gradational. With these rocks are associated other types of less importance.

Garnet-Mica Schist with Little Graphite.—In hand specimen this rock is typically a dark mica schist with many small red garnets. In thin sections the chief minerals are quartz, biotite, and garnet, with or without feldspar. The commonest accessories are sillimanite (fibrolite), muscovite, magnetite and zoisite, and rarely rutile. Pyrite, found in some sections, probably would be common if unweathered specimens were easily obtainable. Alteration products include chiefly sericite, kaolin and limonite.

As a rule quartz constitutes 50 to 60 per cent. of the rock. The grains are either small and much sheared and comminuted or larger and sometimes suggestive of injected matter. Feldspar ranging from orthoclase to basic plagioclase is generally present, often only accessory, but occasionally dominant. In more or less weathered specimens it is apt to be altered to kaolin, or sericitic aggregates.

Garnet forms metacrysts rarely exceeding 5 millimeters in diameter, and always full of inclusions of quartz, mica, and other minerals. The garnet is often much fractured and partly altered

to brown, limonitic matter. The biotite is deep brown with a purple tinge at its position of maximum absorption. More or less muscovite is generally present. The micas and sillimanite, assisted by elongated patches of sericite, are the chief cleavage makers. Sillimanite occurs as sheaves of fine fibers often bending around garnet crystals and quartz masses. A trace of graphite usually is present, even when unsuspected in the hand specimen.

This type, therefore, resembles closely the Altered Ashland, or non-graphitic garnetiferous schist, differing chiefly in the greater abundance of quartz, and in the smaller quantity and more variable quality of the feldspar. The soil it yields is also similar to that previously described, generally of a reddish color with a spotted and variegated subsoil.

Other Varietal Phases.—Within the garnetiferous mica schist are narrow bands of distinctive character that may be followed a considerable distance. An ultra-siliceous type composed chiefly of quartz, a little garnet and traces of other minerals is common and thick bands are conspicuous ridge formers. In another type the garnet increases notably and may form 30 to 50 per cent. of the whole rock. The crystals increase in size to about ¼ inch, and take on a spherical shape, although they are still poikilitic in thin section. At places these rounded garnets, badly decomposed, cover the surface in great numbers. On float blocks they etch out in strong relief. This type also resists erosion well and forms ridges, such as the crest of the high ridge in sections 21 and 22, T. 20 S., R. 7 E., between the Griesemer and Alabama No. 1 mines. The unweathered rock is exposed in the tunnel through this ridge at the Griesemer mine.

A band of peculiar rock in the series is found about 500 feet southeast of Griesemer mill on the trail leading up to the mountain cut and just south of the narrow band of hornblende schist shown in Fig. 1. It is 6 or 8 feet wide and resembles a light brown, thin-banded quartzite. It is unusually dense and heavy. Thin section shows about 40 per cent. quartz; about 30 per cent. tiny garnets free from fractures or crushing effects, not poikilitic

as is the rule elsewhere, and often showing good crystal outline; considerable zoisite-epidote in patches; and traces of accessories and alteration products. This band can be traced for some hundreds of feet, and a similar band, probably identical, occupies the same stratigraphic horizon in a section along a road one mile southwest.

Graphitic Schist.—Fresh unweathered graphitic schist, commonly called "blue rock," can be seen in the lower parts of many of the graphite pits. Hand specimens are typically gray due to the mixture of black graphite with quartz and other light colored minerals. Cleavage is perfect and regular except where injection effects become visible, lending the rock a gneissic or banded appearance. Quartz, muscovite or sericite, graphite and pyrite, are the only minerals distinguishable in the hand specimen. Mica or pyrite may fail occasionally. Feldspar is present only in material that is clearly of pegmatitic nature.

Weathered material, such as constitutes the bulk of the ore, has a rusty color ranging between red and yellow, due to iron oxide from the decomposed pyrite. The graphite flakes are more prominent than in the "blue rock." Foliation planes open up extensively, and some of the rock is so soft that it crumbles in the fingers. Quartz and mica are still visible, but the feldspar of the pegmatite usually is thoroughly kaolinized.

Even in thin section, the mineralogy of the graphitic schists is remarkably simple. Quartz, dominant, makes up three quarters of the rock. Muscovite and sericite together are the next most abundant constituent. Graphite generally makes up less than 10 per cent. by volume of the rock. Pyrite in considerable amount almost invariably accompanies graphite in the unweathered rock. Sillimanite (fibrolite) is the only abundant accessory, but is absent in many sections. Zoisite and rutile appear sparingly in numerous sections. Feldspar was noted in only a few sections.

The relations of these various minerals have an important bearing on the origin and economic value of the graphite, but inasmuch as graphite also occurs in and is related significantly to

the intrusive matter the detailed description of its occurrence is deferred until later.

The graphitic schist is intimately associated with the garnetiferous mica schist, and the two grade into each other both laterally and along the strike. The graphitic schist, therefore, forms lenses of considerable extent in the more extensive and generally non-graphitic schist. A conspicuous feature is the mutual exclusiveness of graphite and garnet. Where garnet is abundant, graphite never approaches commercial quantity; and where graphite is conspicuous, garnet almost or entirely disappears. Somewhat the same relation holds true for biotite, which occurs mainly in the least graphitic rocks.

The soil yielded by the graphitic schist is gray, often full of quartz fragments and gravel; subsoils are not uncommonly spotted and variegated in color. The rock has no conspicuous topographic expression, since it is intermediate in resistance between the weaker hornblende schists and the harder siliceous or garnetiferous types previously described. The graphite bands crop out commonly on slopes or just below the crests of ridges.

ASHLAND SERIES—INTRUSIVES.

Acid intrusive matter with a considerable range in composition and texture has invaded in enormous quantity all the formations previously described. The writer's study covers too small an area to permit of broad generalization, but seems to be in harmony with Prouty's conclusion [14] that virtually all the intrusive material is related closely to those large areas of gneissoid intrusives to the southeast known as the Bluff Springs granite and the Pinckneyville granite.

Personal observations did not extend southeast beyond the Ashland-Millerville highway, but even along this road some large bodies of gneissoid intrusive can be found, although the exposures are poor. There are two more or less gradational types of gneiss, a dark variety containing biotite and a white variety con-

[14] Prouty, W. F., "Geology and Mineral Resources of Clay County," Geol. Survey of Alabama, County Report No. 1, 1923.

taining muscovite. Gray plagioclase feldspar is the dominant mineral, with quartz of secondary importance. Generally the rock is imperfectly banded, and often it exhibits a crushed appearance. The areas of gneiss include many patches of schist and seem at places to have assimilated them, producing an intermediate rock. Areas of gneiss often can be distinguished by the peculiar whiteness of the soil; moreover, they are less resistant to erosion than the schist and tend to form lowlands.

Intrusives of the Graphitic Area.

Intrusives observed in the graphitic area comprise 3 classes: (*A*) dikes of a gneissoid intrusive, approximately quartz diorite, (*B*) aplite dikes, (*C*) veins of pegmatite and quartz, chiefly in lit-par-lit injections. Type (*A*), by inference, represents the earliest offshoots of the great batholith. Type (*B*) occupies faults and fractures cutting type (*C*) and would seem to be the latest. All three presumably represent one great period of igneous activity. Types (*A*) and (*B*) are rare and unimportant.

A. Gneissoid Intrusive Dikes.—Five gneissoid intrusive dikes ranging in thickness from 7½ to 50 feet were observed in or near the graphitic belt (Fig. 1). The rock is generally a rather fine-grained quartz diorite in which gray feldspar predominates, and quartz is sparingly present. Biotite is commonest, but muscovite may occur. In a thin section from the May Brothers mine the feldspar is plagioclase, approximately labradorite. Zoisite and magnetite are accessories. The gneissic structure is indistinct, and there has been some little fracturing of the feldspars.

These dikes, so far as observed, are not cut by the pegmatite and quartz veins, probably chiefly because they resisted injection more effectively than the cleavable schists.

At the Hood-Graves mine, the gneissic dike, which is at the footwall of the ore body, contains along its borders numerous inclusions of fine-grained graphitic schist, but graphite was not found in the gneiss in any other relation and the intrusive seems

to have had little or no effect upon the graphite even near its walls.

B. Aplite Dikes.—Small dikes of fine-grained granitic material were seen at several places. An especially good example is at the head of the quarry at the National Graphite Co. mine, where a dike 6 to 8 inches wide extends vertically the full height of the cut, about 50 feet. Two similar dikes are well exposed in the footwall of the No. 1 or northern cut of the Alabama No. 1 mine. They are about 30 feet apart, are 10 or 12 inches thick, and cut the strike of the schists. In these and other cases the dikes seem to have been intruded along faults or joints that cut the structure of the schists and of the included lit-par-lit veins of quartz and pegmatite.

The aplitic matter seems to consist mainly of gray feldspar with a little quartz and mica. Traces of graphite, seemingly derived by entanglement from the wall rock, are occasionally present. The rock always is badly weathered.

C. Pegmatite and Quartz Veins.—Veins of quartz and pegmatite constitute the great bulk of the intrusive matter and the only part of direct importance concerning graphite. All gradations may be found between veins of pure quartz and veins of nearly pure, coarse feldspar. In general the smaller veins, less than a foot in thickness, consist most often of pure quartz, whereas the larger veins, which attain a maximum thickness of 8 or 10 feet, are apt to be true feldspathic pegmatites. Exceptions occur both ways. Certain phases of the pegmatites are fine-grained and approach granite in composition and texture.

Mineralogically the pegmatites are of simple composition, consisting chiefly of quartz and feldspar. Mica may be absent or present in considerable amount, sometimes in bunches of flakes exceeding an inch in diameter. Indeed, commercial mica has been mined at several places bordering the graphitic belt on the northwest. Both biotite and muscovite are found, but the latter predominates. Graphite may or may not be present both in the pegmatites and in the quartz veins.

The feldspar usually is gray or white and seems commonly to

be a medium basic plagioclase although orthoclase and microcline also are found. Unweathered feldspathic material is hard to obtain. At numerous places the feldspar has been dissolved leaving quartz with a sort of honeycomb texture. Accessories are notably uncommon, and of erratic distribution. Green beryl and black tourmaline were noted at a prospect pit on a large pegmatite vein near the south quarter corner of sec. 15, T. 20 S., R. 7 E.

The vein matter as a rule lies parallel to the schistosity, and pinches and swells rapidly. Similar veins also occur less frequently cutting the schistosity of the inclosing rocks. Single veins ordinarily cannot be traced more than a few feet, or at most a few hundred feet along the surface or in mine workings, but a few are more persistent. A coarse micaceous pegmatite several feet thick in the south part of sec. 15, T. 20, S., R. 7 E., was traced continuously for about 1,500 feet.

The amount of injected matter is enormous, probably constituting at most places from 10 to 50 per cent. of the present volume of the graphitic and non-graphitic garnetiferous schists. At a favorable place in the Monitor mine (SW. ¼, sec. 5, T. 20 S., R. 8 E.), where on casual inspection the rock seemed virtually free from injected matter, careful measurement for 60 feet perpendicular to strike and dip showed 41 visible quartz veins totaling 53 inches in thickness, or 5 per cent. of the total section. Only 3 veins, respectively 15 in., 6 in. and 4 in. thick, exceeded 1 inch in thickness. The smallest measured ⅛ inch thick.

Thin sections of the graphitic schists, and of the non-graphitic garnetiferous schists as well, show that the injected matter is not all visible to the eye. It permeates the very fabric of the schist constituting 20 to 30 per cent. of the rock in sections where igneous influence in the hand specimen is unsuspected. These features are elaborated in describing the occurrence of graphite.

STRUCTURE.

Schistosity and Bedding.—The dominant structural feature of all the formations is their prominent cleavage or schistosity, which, at places, especially where visible injection is prominent,

may grade into something more like a gneissic banding. In a general way the strike of the schistosity seems to correspond to that of the bedding, as is apparent from a comparison of the strike and dip symbols (Fig. 1), all measured on cleavage, with the trend of outcrop of the formations. All mining and prospecting for graphite is based on the theory (not necessarily true) that the ore will follow the strike and dip. Actual contacts where the relation between cleavage and bedding may be compared are few and poor. The contacts of the hornblende schists with the adjacent schists are exposed at a number of places in road cuts and entryways to mines. At the Acme mine, the Eagle mine, the Ceylon mine in Coosa County, and elsewhere they seem to indicate that bedding and cleavage are conformable, but the exposures are only 10 or 15 feet in height and rather badly weathered. At the small northern cut of the May Brothers mine the cleavage of the graphitic schist and hornblende schist seems not to correspond but the discordance may possibly be due to faulting.

Folding.—A glance at the map (Fig. 1) will indicate that the rocks of the region have suffered intense folding. This folding presumably preceded, or possibly in part accompanied, those movements and stresses which caused recrystallization and produced the schistosity that has destroyed so much of the evidence as to the original stratigraphic and structural relations. Presumably the beds were crumpled into close, probably overturned, folds dipping steeply to the southeast, and on these the schistosity has been superimposed with a fair degree of conformity to the bedding. The evidence is clear, but could not be fully worked out in the time available, that definite closed folds exist at places such as in sections 9–10–15–16, T. 20 S., R. 7 E.

It would seem to be a logical assumption that many of the persistent bands of hornblende schist which prevail throughout the graphitic belt, and many of the numerous graphite leads as well, have been repeated by folding or faulting, chiefly folding. The beds, however, vary so rapidly from place to place, that with only lithologic evidence available it is hazardous to attempt a correla-

tion. The writer with compass and hand level very carefully paced a section and profile across the heart of the graphitic belt in the hope of being able to correlate the different ore zones and the intervening hornblende schists. This section is shown in Fig. 2, without any attempt at structural interpretation. The

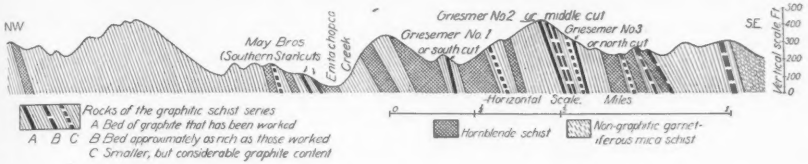


FIG. 2. Profile and section along line *A–B*, Fig. 1.

section in which the belts of hornblende schist are commonest may possibly represent a huge fold, either synclinal or anticlinal. An anticlinal structure would seem to imply that the graphitic schist and the hornblende schist are older than the broad belt of non-graphitic schist to the southeast, which appears improbable. The whole series may perhaps be monoclinal, and correlate with some similar broad belt to the northwest, but this necessitates assuming a rather excessive thickness of beds. The repetition may be due to faulting, but this explanation is not favored for reasons given later.

An important amount of later folding affecting this schistosity has occurred at a few places, sometimes resulting even in a reversal of the dip of the cleavage. Thus at the Republic mine north of Ashland one can see, east of the mine in the cut along the haulage track, good exposures of schist with cleavage dipping normally southeastward. Westward along the haulage cut of the mine, the dip gradually reverses and in the ore cut here, and at the neighboring Conklin mine, the dip is 20 to 30 degrees to the northwest, and exhibits minor flexures and folds. A similar anticlinal fold of the cleavage is completely exposed in a big cut on the Atlanta, Birmingham and Atlantic railroad, about half a mile east of Pyriton. It is questionable, however, whether the schistosity at all places of reversed dip owes its present unusual

attitude entirely to later folding. It may possibly have differed originally from the prevailing structure at some places.

That folding which is clearly later than the schistosity naturally affects the lit-par-lit intrusives in the same manner as the inclosing schists.

Faulting.—Several faults and hypothetical faults of great magnitude are indicated in Prouty's sections. All are thrust faults, most but not all of them dipping to the southeast. Their strike is roughly parallel to that of the formations, usually along contacts. None are within the graphitic zone of Fig. 1. Such faulting is generally considered typical of Piedmont and Appalachian structure, and might naturally be expected. Within the area of Fig. 1, however, no clear evidence of such faults was obtained. Certainly if faults of any great magnitude exist, as seems improbable, they must conform remarkably well to the strike of the formations. Otherwise significant offsets would be found in tracing the beds. Numerous small faults both normal and reversed can be seen in almost any road cut or quarry.

GEOLOGY OF THE CEYLON MINE, COOSA COUNTY.

In order to compare the geology of the graphite deposits around Ashland with that of the second large graphitic belt to the southwest, a day was spent at the Ceylon mine, one of the most important properties in Coosa County. This mine is in the northern part of the county, a few miles west of Goodwater or south of Hollins.

The ore crops out on a high, rounded ridge that trends northeast-southwest parallel to the strike of the underlying schist, which dips steeply to the southeast. The ore-bearing rock is a siliceous, somewhat micaceous, graphitic schist with strong evidence, both in the field and under the microscope, of injection by igneous material. The workable ore-body varies from 25 to 50 feet in thickness. The graphite content gradually diminishes to the southeast and 200 or 300 feet from the ore-body virtually disappears. To the northwest, richly garnetiferous mica schist containing only a microscopic trace of graphite is exposed for ½

mile or more. Fifty to 100 feet from the footwall of the ore zone is a broad band 250 or 300 feet wide of fine-grained hornblende schist. The weathered contact is exposed in the walls of the haulage cut. Similar exposures of the hornblende schist are found in roadcuts to the northeast. Small, badly weathered but unmistakable float fragments mark the outcrop. Southeast of the ore body about 500 or 600 feet, in a deep valley, is another similar band of hornblende schist apparently about 200 feet wide, which was traced for several hundred feet. Some of the float resembles the hornblende diorite of the Ashland area.

From this brief description it is clear that the geology of the Ceylon mine differs in no essential feature from that at Ashland. The two large graphitic areas doubtless represent parts of what was once a continuous series of formations.

AGE OF THE ASHLAND SERIES.

Some confusion exists in the scattered literature of the Alabama graphite deposits as to the age of the Ashland series. In early days it was commonly assigned to the Archean (pre-Cambrian) complex. Prouty [15] states that the Ashland rocks are the oldest in the area, and are unconformable with all other formations. If the Talladega, as supposed, dates back to Cambrian, this would put the Ashland in the pre-Cambrian. Such a conclusion harmonizes well with the metamorphic features. The suggestion of Prouty that the Ashland is roughly equivalent to other pre-Cambrian graphitic formations of the Piedmont in Carolina, Pennsylvania, and New York, also seems reasonable. It appears likely that the dynamic disturbances and the igneous injection which caused or accompanied the intensive metamorphism of the Ashland and the milder metamorphism of the Talladega, took place near the close of the Carboniferous. The injected matter in the Ashland, therefore, considered alone, might be called Carboniferous.

[15] *Op. cit.*, p. 61.

ORIGINAL NATURE OF THE METAMORPHIC ROCKS.

General Features.—On the basis of structure it appears that the greater part of the rocks in the graphitic belts must originally have been stratified sedimentary beds. Folding and metamorphism have converted them into schists, now outcropping in many parallel bands, which still exhibit inherited lithologic differences. The rapid variations from type to type both along and across the strike indicate that the original sediments probably were clastic, rather variable in composition, and lenticular in shape. This is particularly true of the graphitic schists and of the non-graphitic micaceous and garnetiferous schists, less true of the hornblende schists, although these also have characteristic but less rapid variations in composition and thickness. Some of the variability in thickness is due to the different degrees of squeezing and injection, but much of it must be inherent.

Micaceous Schists.—From the mineralogy of the schists we may infer something as to the original nature of the sediments. The non-graphitic, garnetiferous mica schist is composed on the average of 40 to 60 per cent. basic plagioclase, 25 to 30 per cent. quartz, 5 to 10 per cent. each of garnet and biotite, with accessory sillimanite and magnetite and traces of graphite; muscovite may partially supplant biotite. The garnet is an iron variety, probably manganiferous, and the biotite may also be manganiferous. It is certain that part of the quartz, and perhaps some feldspar is injected, but, even making allowance for this condition, the rock must still have been some sort of arkose or graywacke, since structural features indicate clearly that it was originally of sedimentary origin.

The graphitic schists average about 75 per cent. quartz, 10 per cent. of muscovite and sericite together, a few per cent. each of graphite and pyrite, with traces of accessories, none of which, except sillimanite, ever assumes compositional significance. A good deal of the quartz may often be attributed to injection but this makes no radical change in the remainder. Most, if not all, of the pyrite was introduced during the later stages of injection.

Disregarding the carbon content for the present, and assuming again that structural features indicate clearly a sedimentary derivation, the original cannot have been anything but some sort of more or less aluminous (clayey ?) sandstone.

The total absence of carbonate compounds is one of the striking features of these rocks. Both the graphitic and the non-graphitic garnetiferous mica schists seem to have been unusually free from limey matter. Such calcium as is represented by the basic plagioclase of the non-graphitic phases probably represents original or introduced feldspathic matter. Otherwise it would seem that calcium should appear as a prominent constituent of the garnet at least, and perhaps of other metamorphic minerals as well.

Hornblende Schists.—As a rule the hornblende schist contains about 40 to 45 per cent. each of basic plagioclase and of a hornblende low in iron. Clear, magnesian pyroxene up to 5 or 10 per cent. may or may not be present. Titanite up to 1 or 2 per cent. is an invariable constituent. Other accessories are erratic, and not of compositional significance, although some, such as olivine, are of diagnostic importance in considering the origin of the rock. Merely on the basis of composition one would suggest that the hornblende schist is an altered basic igneous rock.

The hornblende diorite seems to have identically the same composition as the fine-grained schist. Its texture and nearly massive structure, however, suggest strongly an igneous rock only slightly modified.

The "cortlandtite" is most puzzling. Typically it contains 50 per cent. or more of pale green hornblende, very low in iron, and 20 to 30 per cent. of clear magnesian pyroxene. A few per cent. of green spinel and slightly less magnetite are invariably present. Magnesian olivine may appear in considerable amount. The rock has all the earmarks of a true igneous intrusive. Yet it seems to be confined strictly to areas of the hornblende schists, a strange relation for an intrusive, unless it is genetically related to the enclosing schists.

The difficulty of explaining the origin of the hornblende schists

and their peculiar related types is illustrated by the reports of the Alabama Survey, which contain numerous references to them. In the earlier reports they are referred to most often merely as basic rock, at other times as amphibolite, hornblende schist, diorite schist and diorite gneiss. From Prouty's[16] detailed report it seems certain that the area of "basic (igneous) rock" he has mapped in the northeast corner of Clay County is really the same as the hornblende schists of the graphitic area near Ashland. Prouty asserts (p. 59) that a part of the amphibolite schists in the Ashland series was originally of basic igneous character. Yet two pages later, he states that "the present hornblende schist areas represent, it is thought, in part at least, beds and lenses of limestone or calcareous sediments." And still farther on in his detailed sections of the graphite areas he refers to them more or less indifferently as hornblende schist, diorite schist, or simply diorite.

At least three possibilities must be considered as to the original nature of these rocks. They may represent (1) metamorphosed magnesian limestone or calcareous shale, (2) basic extrusive flows (less probably tuffs), (3) basic intrusive sills. The sedimentary hypothesis would readily explain the number persistence, and perhaps the uniformity in composition of the beds, as well as their intercalation in the graphitic series. But it fails to account for the sudden transitions from ultra-siliceous graphitic schists to rocks in which original quartz is unknown. Derivation from limestones would seem to imply the elimination completely and uniformly over very large areas of enormous amounts of calcium, and it seems impossible that this element would not frequently have persisted in minerals such as garnet, tremolite, and wollastonite, or even calcite. This explanation also fails completely for the masses of hornblende diorite and "cortlandtite."

Either the second or the third hypothesis would explain very well the sharp contacts with the graphitic schists and would also account for the absence of original quartz, the present chemical composition of the rocks, and the presence of minerals such as

[16] *Op. cit.*

olivine. Intrusion as sills would explain the intercalation with the graphitic schists, better than would extrusion as flows. It would also best explain the presence of the hornblende diorite and of the "cortlandtite." The latter probably should be regarded as a very basic magmatic segregation, in place, and the former simply as unaltered remants of the original rock, the chemical composition of which, on such an assumption, need scarcely have been modified in anyway. The "cortlandtite" seems to have been more resistant to shearing stresses than any other rock in the area, and the rather common association with it of the uncrushed hornblende diorite probably is due to the fact that the adjacent masses of "cortlandtite" assumed much of the load and protected the diorite from excessive shearing.

The writer believes, therefore, that the third explanation, intrusion as basic sills prior to the folding and metamorphism, accounts adequately for all the observed facts of the field relations of the hornblende schists and the included diorite and "cortlandtite," and that no other explanation fills these requirements. The association of these intrusives with the graphitic schists points apparently to some feature in the original intruded sediments which caused localization of the sills at certain horizons.

GRAPHITE.

Character of Leads.—The numerous beds of graphitic schist which have been worked are frequently referred to as leads. They vary in thickness from a few feet up to 100 feet or more in rare instances. Ordinarily leads less than 15 or 20 feet thick cannot be mined advantageously. This is particularly true where the ore is inclined at intermediate angles such as 30 to 60 degrees. In open cut mining a great deal of waste must be removed from the hanging wall or much ore left to support it. Steep or vertical dips facilitate the mining of narrow leads. The rare case where the dip is so flat that it corresponds to the hill slope might seem to be ideal, but where it exists the ore seems to be oxidized much less deeply and blue rock soon prevents mining. The deepest weathering has occurred on smooth, well-drained ridges where

the cleavage has a steep dip. A combination of these favorable circumstances together with a good ore body has made the Quenelda mine probably the largest total producer and one of the few profitable mines in the area. The average thickness of leads mined probably is 30 to 40 feet and the average dip 45 to 60 degrees.

Several leads in the region have been opened for a distance of 500 feet or more along the strike. Those shown in Fig. 1 are drawn to scale in length but not in width. At the Ceylon mine the length of nearly continuous cuts is about 750 feet and there is considerable more proven ore at either end.

Under present mining conditions, where only the oxidized ore is sought, the persistence of ore leads depends rather more on topographic features than on geologic conditions. Cuts usually are opened either from an entryway along some divide between ravines with tracks and headings in each direction, or along some valley with headings leading in opposite directions into the hill. Good ore, oxidized to a depth of 50 or 60 feet, may be found between ravines, but in the valleys this soft material has usually been eroded, and blue rock is very near the surface. Water also gives trouble in sinking between some of the ravines, and the desire to lay haulage ways in the cuts as nearly horizontal as possible conflicts with any attempt to make the depth of cuts uniform below the surface. Consequently the available ore along a promising lead may be only a fraction of its apparent volume.

Many of the leads have been blocked out for some hundreds of feet by systems of prospecting trenches 2 or 3 feet in depth. It is generally impossible to trace them very far by natural exposures. An unusually large and favorably situated lead in the north part of sec. 22, T. 20 S., R. 7 E., on the Griesemer property was followed northeast from the southern or No. 3 Griesemer cut for about 4,000 feet by nearly continuous small exposures in ledges, gullies, and ravines and finally was lost in an area covered by deep soil. Its width throughout this distance seemed to range from 50 to 120 feet. Careful prospecting or actual working would be required to determine whether all of this is workable

ore. Much of it, too, is cut out by a series of deep ravines. No effort was made to trace the lead in the opposite direction, but it is believed to continue for a considerable distance.

In general the leads seem to persist for some hundreds or even thousands of feet, but often drop below the desired grade, or are cut by horses of lean material or of barren injected matter, particularly by large quartz and pegmatite veins. These are often left standing in the cuts.

It is commonly and reasonably supposed that certain well-known leads on which important mines are situated are the same. The actual correlations made, even by mining men, however, seem to have been rather inaccurate. The map (Fig. 1) shows that the No. 1 or northern cut of the Griesemer mine and the corresponding northern cut of the Alabama No. 1 property are very nearly if not exactly on the same lead, and perhaps correspond closely to the lead developed at the Eagle and Superior Flake mines. The No. 2 or mountain cuts of the Griesemer, and the Southern cut of the Alabama No. 1 property, lie within the same wide band of schist but at horizons 200 or 300 feet apart if one takes the hornblende schist to the north as a reference horizon, and it seems likely that the Alabama cut corresponds to some similar but very lean graphitic schist about midway between the Griesemer cut and its next northern band of hornblende schist. The Allen mine, containing some of the richest graphitic schist in the district, corresponds to nothing else unless possibly the Ashland, one of the poorest prospects in the district. The Quenelda corresponds to nothing but the adjacent Old Allen. The Redding, Southern Star, May Brothers, Axton-Noe and Alabama No. 2 mines occupy the same graphitic band, but seem to have rather variable positions within this band. Emphasis should be placed on the fact that the area shown on Fig. 1 seems to be of more simple structure than much of the region to the northeast and exact correlations in those localities would be even more difficult, because of minor faulting and folding, especially the folding that is later in date than the schistosity. This is an important consideration in mining, for the more disturbed the leads are, the more difficult they are to follow.

Graphite Content.—Although private parties have analyzed numerous samples of the graphite ores, almost no data as to the actual graphite content seem ever to have been published. Dub and Moses[17] state that the ore "averages about 2½ per cent. graphitic carbon." Mine operators give estimates ranging from two to ten per cent. The latter undoubtedly is exaggerated as the best ore, for instance, at the Ceylon mine can scarcely exceed 5 to 6 per cent., and the average probably is nearer 3 per cent. The writer obtained four samples from different leads for the purpose of checking roughly the general carbon content of the ores. The samples represent small continuous trenches across the full width of the ore. They originally weighed 40 to 80 pounds, and were cut and quartered in the field to convenient size.

Three of the samples were collected on the Griesemer property as facilities were more convenient there, but they are sufficiently like other leads to be representative.

All the samples represent oxidized ore, and since the carbon is inert it might be expected to run a little higher than in the blue rock, although some mining men, judging solely by appearance, assert that the latter is richer.

Petrography of the Graphitic Rocks. Normal Ore.—By normal ore is meant that which is comparatively free from visible injected matter, particularly the larger veins. The mineralogy, as previously described is simple. The occurrence and mutual relations of the different minerals are important both economically and with respect to the origin of the graphite, and will be described briefly.

QUARTZ: Quartz may be in either of two rather distinctive forms. One form consists of very small grains quite irregular in shape and size ranging generally from 0.1 to 0.5 millimeter in length, and commonly elongated to from two to three times their thickness, parallel to the rock cleavage. These grains represent recrystallized original material and show strongly the effect of

[17] Dub, G. G., and Moses, F. G., "Mining and Preparing Domestic Graphite for Crucible Use," U. S. Bur. Mines Bull., 112, p. 12, 1920.

dynamic forces, as represented by evident comminution, abundant strain shadows, and intermingling with sheared masses of sericite, and with small graphite flakes (Pl. I., *A* and *C*).

TABLE I.

ANALYSES OF ALABAMA GRAPHITE ORES.[18]

Analyses made by Dr. W. D. Turner, Professor of Chemistry, Mo. School of Mines and Metallurgy.

No.	Source.	Width Normal to Strike and Dip, Feet.	Remarks.	Total C. Per Cent.
1	Griesemer No. 1 or N. cut.	32	Across heading; many quartz and pegmatite veins.	2.90
2	S. end of Griesemer Tunnel (near No. 2 or Mt. cut)	16	Small rich lead, not mined, much oxidized and soft.	3.04
3	Griesemer No. 3 or S. Lead	70	Weathered outcrop stripped for mining; east end of cut; Some lean streaks.	2.41
4	Allen Mine.....	6.3	Some of richest ore in good ore body. Much Oxidized and soft.	3.44

Sample No	Absorbed Moisture, Per Cent.	Volatile Matter (Chiefly Combined Water), Per Cent.	Total Combustible (Including Combined Water), Per Cent.	Fixed Carbon. Per Cent.	Ash, Per Cent.
1	0.69	2.80	5.74	2.94	93.57
2	0.42	3.45	6.47	3.02	93.11
3	0.35	3.50	5.85	2.35	93.90
4	0.18	2.99	6.41	3.42	93.41

[18] Doctor Turner explains the second set of determinations as follows:

"Absorbed moisture was determined by drying a 1-gram sample at 105° C. for one hour; volatile matter by igniting in a platinum crucible at 800° C. for 3 minutes; total combustible by igniting in an open crucible at 1000° C. to constant weight; fixed carbon = total combustible—volatile; ash = residue after igniting at 1000° C. to constant weight. Total carbon given in the first table was determined by burning a 1-gram sample in a stream of oxygen and weighing the CO_2 produced; for this determination the ore was first treated with HCl to remove carbonate."

Fixed carbon and total carbon check so closely as to be virtually equivalent.

Quartz of the other form is in considerably larger grains, often 0.5 to 0.8 millimeter in diameter, less notably elongated and more uniform in size. It also is relatively free from included masses of sericite and graphite, although it often contains much larger and more perfect graphite flakes. This form of quartz has a tendency to occur in streaks or bands, often alternating with quartz of the other variety and with streaks of mica and sillimanite so as to give the rock an appearance of microscopic gneissic structure, similar to that produced by visible injection of narrow quartz bands. This, indeed, is believed to be its true explanation. The greater size, uniformity and purity of the quartz grains, their streaked arrangement and the peculiar manner in which at some places they send out offshoots through the adjacent rock and at other places include fragments evidently torn from their walls indicate that they are veins as truly as the massive pegmatites. These features are shown in Pl. I., *B* and *D*. The two varieties will be designated hereafter recrystallized quartz and injected quartz, respectively.

The quantity of injected quartz, even in specimens carefully selected as being free from visible injections, is surprising. It may amount to from 25 to 50 per cent. of the total rock and on the average probably exceeds 10 per cent. Both varieties of quartz may be considerably fractured. Prominent cross fractures are especially characteristic of the injected quartz.

MICA: Clear muscovite flakes seldom exceeding 0.5 millimeter in length are generally present. Small sheaves of flakes, occasionally interleaved with graphite, are not uncommon. The flakes are generally well oriented and most often lie between quartz grains, but their ends frequently project into adjacent grains, and sometimes they seem to cut directly through the quartz.

Sericite in aggregates or patches elongated parallel to the schistosity is generally more abundant than muscovite. The patches of sericite frequently include particles and small flakes of graphite. In rare cases this sericite may be a hydrothermal alteration product of feldspars, but the scarcity of the latter

seems to indicate that most of the sericite is an original product of recrystallization.

Biotite is rare. Its occurrence does not differ essentially from that of muscovite and the two are commonly associated.

FELDSPAR: A few grains of orthoclase, probably of injected origin, were found in one section from the Ashland area (Hood-Graves mine). One section from the Ceylon Mine contains about 20 per cent. of plagioclase at least as basic as labradorite. The grains are about the same size as the quartz grains but less elongated, and are partly altered to sericite. They probably represent an original product of recrystallization.

SILLIMANITE: Sillimanite needles in small bundles generally associated with sericite are fairly abundant in some sections, and entirely absent in others (see Pl. II., *B*). The mineral evidently is widely distributed for pannings of heavy minerals from three tailings piles, the Redding, Griesemer, and Alabama No. 1 (see below) all contained about 50 per cent. of it.

ZOISITE: Zoisite is an erratic accessory forming small grains of very irregular shape, exceedingly fractured.

RUTILE: Rutile appears occasionally as golden yellow, semi-transparent grains with black borders.

OTHER ACCESSORIES: The three samples of pannings from tailing piles mentioned under sillimanite, yielded a few minerals not noted in thin section. All three contained a trace of magnetite. Hematite, with attached particles of white minerals, is fairly common. In the Griesemer sample a dark green isotropic mineral of high index, possibly hercynite, is abundant. The Redding sample has considerable light green to brown and rather faintly pleochroic tourmaline. Apatite and rutile were noted. The tourmaline and apatite and the hercynite (?) are probably igneous minerals derived from the pegmatites. The hematite is an oxidation product of the weathered pyrite. The zircon, rutile, and magnetite may perhaps be residual heavy minerals contained in the original sediments.

GRAPHITE: The graphite is usually fairly evenly distributed, but in flakes of unequal size. For example those in the injected

quartz are larger than those in the recrystallized quartz and in the sericite aggregates (Pl. II., *A* and *B*). Their maximum lengths in thin sections frequently range from 0.8 to 1.5 millimeters, whereas in the other association they seldom exceed half that length. The average for all flakes in all sections cannot be more than 0.3 to 0.5 millimeter. All these figures are for sections cut normal to the cleavage of the rock.

As intimated, graphite occurs with both varieties of quartz, perhaps less abundantly but in larger flakes in the injected quartz. In both associations it is generally oriented parallel to the schistosity, usually lies between quartz grains, but frequently projects into adjacent grains, and occasionally cuts directly through the quartz. Its occurrence is much like that of muscovite, with which it frequently, though not characteristically, is interleaved.

Very short flakes of graphite also are abundant in some of the patches of sericite. Associated with these flakes are many irregular, minute black lumps or grains, part of which may possibly not be graphite. These grains apparently are chiefly crushed fragments of graphite, and may form dark swarms or cloudy spots in the sericite. In some sections this comminution of the graphite seems to be partly due to later dynamic movement and crushing. The effect on the flake is injurious.

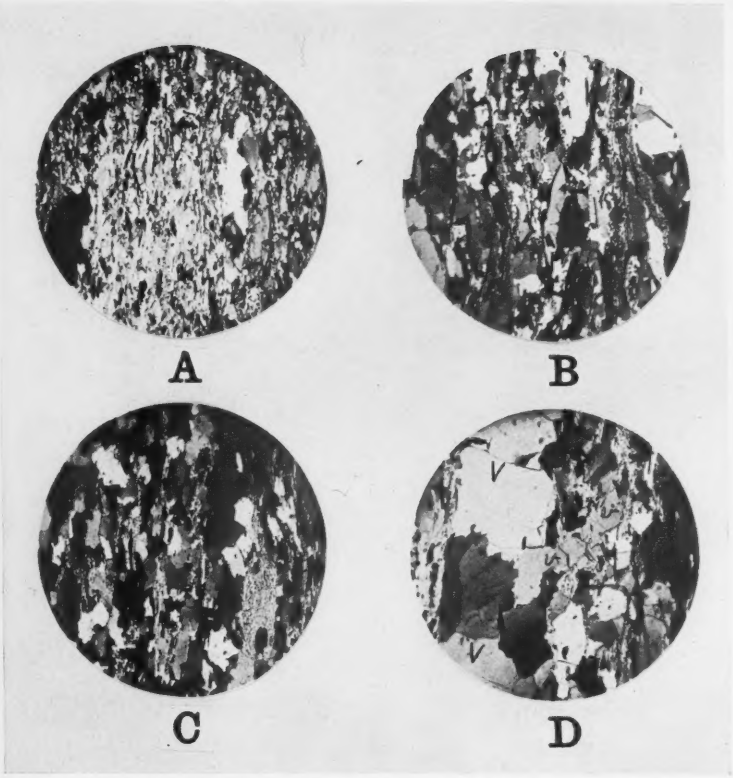
In many sections opaque black or cloudy particles, either in or attached to quartz grains, are abundant. Some appear white and opaque in reflected light, like kaolin. Some have an association with pyrite and a peculiar color suggesting that they may be finely disseminated particles of pyrite. Others contain many specks of black matter, suggestive of graphite, but too small to be resolved even with the highest magnification. They may possibly represent particles of original carbonaceous matter not converted into graphite.

PYRITE: Pyrite is commonly and closely associated with graphite in the unaltered rock. There are several methods of association. The two are in some cases intergrown, pyrite occurring between graphite leaves, or more often filling spaces in the irregular, furry-looking borders of the graphite flakes. Not

PLATE

A
mer
fro
Cro
C
nar
Kin
D
rec
(x

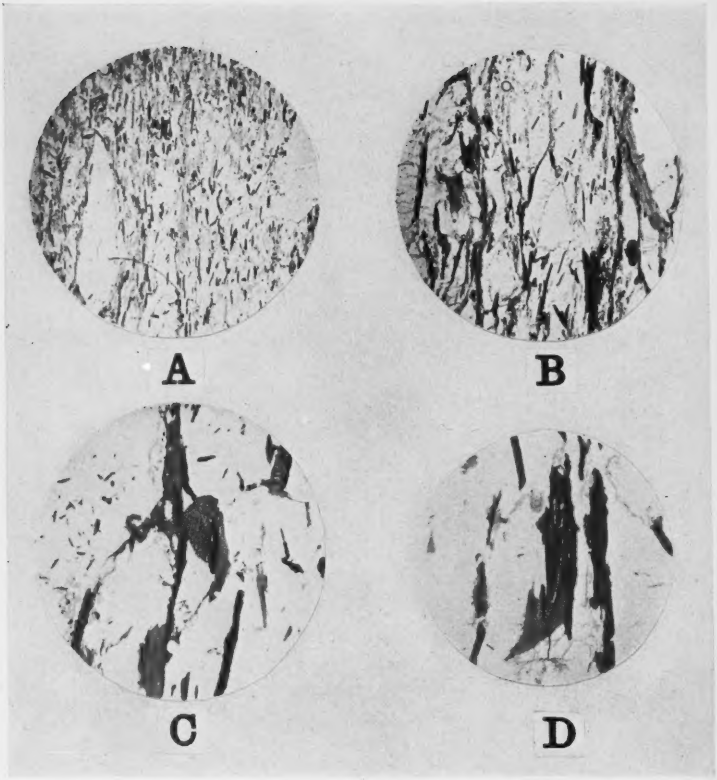
MAY 5 1925 NATIONAL GEOLOGICAL LIBRARY



A and *B*. Photomicrographs showing comparison in size, shape, and arrangement of grain, between recrystallized quartz (*A*) and injected quartz (*B*). *A* from Ceylon mine, Coosa County, *B* from Hood-Graves mine, Clay County. Crossed nicols (x 12). See also Plate II, *A* and *B*.

C. Recrystallized quartz; the larger light and dark grains are quartz; the narrow black streaks are graphite flakes; the mottled patches are sericite. From King mine, north of Ashland. Crossed nicols (x 30).

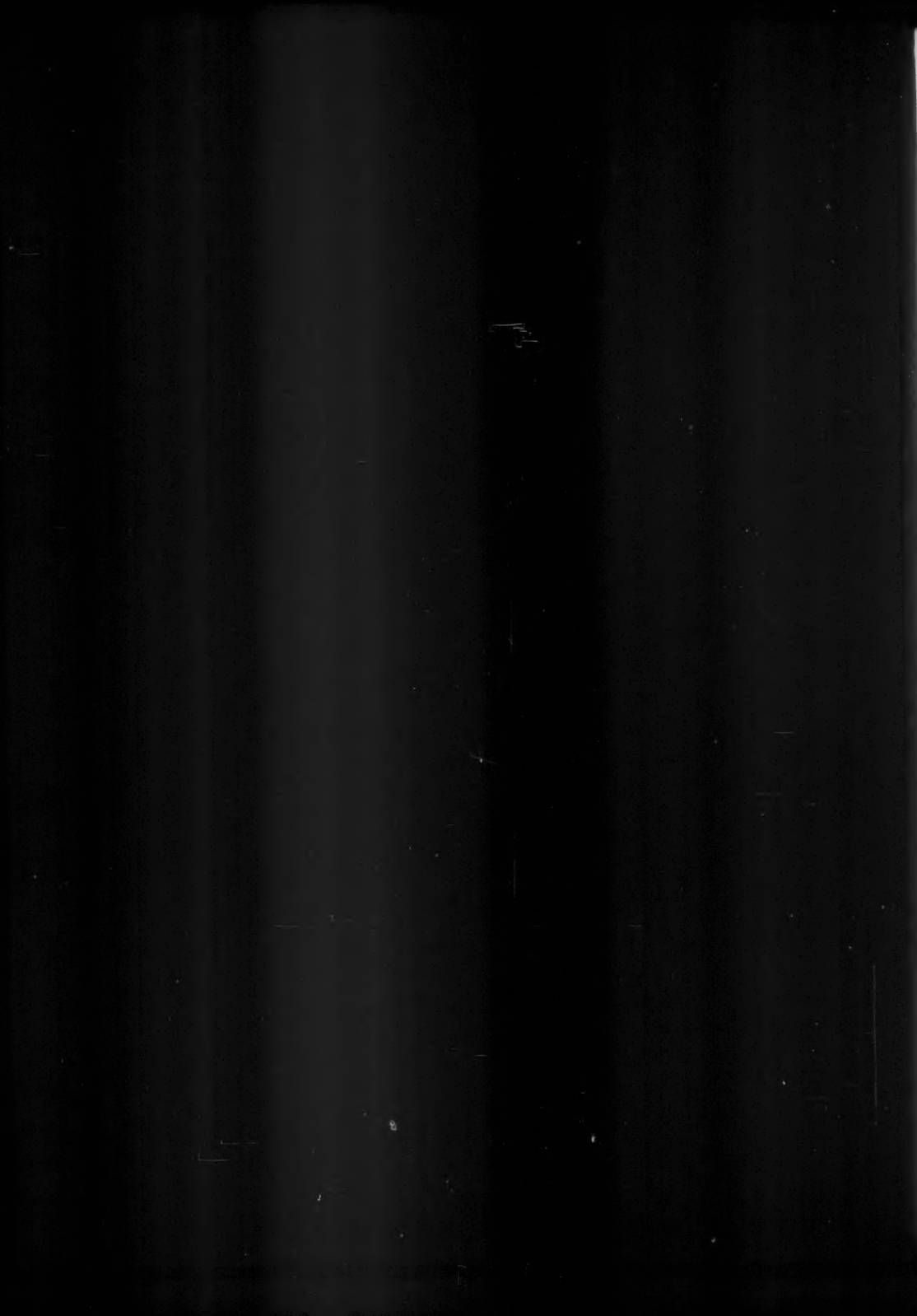
D. Vein of injected quartz (*V–V*) sending an offshoot (*v-v*) into an area of recrystallized quartz, graphite, and sericite. May Brothers mine; crossed nicols (x 30).



A and *B*. Comparative size of graphite flakes in recrystallized quartz (*A*), and in injected quartz (*B*). Same fields shown in Plate I, *A* and *B*, but in ordinary light. The black flakes are graphite; the mottled patches in *A* are sericite; the shred-like patches in *B* are sillimanite. (x 12).

C. Pyrite (gray) enclosing and bordering graphite flakes (black). Smooth gray area at bottom is biotite. Griesemer mine. Reflected light. (x 30).

D. Pyrite (gray) intergrown between ends of graphite flakes (black) with bordering biotite (smooth dark gray). Hood-Graves mine. Reflected light. (x 30).



uncommonly a nearly continuous band of pyrite encloses the graphite flakes. In some instances, the pyrite masses are of irregular shape and attached only at one border to a graphite flake. Occasionally, in the sections, pyrite is not attached to graphite at all, but fills interstices between or fractures in quartz grains. Characteristic associations are shown in Pl. II., *C* and *D*.

The pyrite usually is in formless masses, which at some places contain small reflecting crystal faces.

To some extent, as when they are intergrown, pyrite and graphite seem to be contemporaneous, but some of the pyrite is clearly later, and it is probable that most of it was formed slightly later than the graphite. Pyrite also fills fractures in quartz grains, normal to flakes of graphite and apparently formed after the graphite was in place. The flexibility of the graphite prevented its breaking when the quartz was fractured. The pyrite then must have been introduced well after the graphite had formed. It is probable also that the borders of pyrite around graphite flakes were introduced after the graphite.

The exact genetic relation between pyrite and graphite is uncertain. One is immediately tempted to suggest that the carbon has exercised a reducing action on sulphate solutions, and caused precipitation of pyrite, but this would seem to require actual replacement of graphite by pyrite, of which there is little evidence. Pure carbon, moreover, particularly in the form of graphite, is exceedingly inert chemically, and it is very improbable that it would exert any such reducing action.[19] Possibly the graphite acted merely as a catalyzer. The writer would suggest, however, that either in the crystallization of the graphite or in the immediately subsequent cooling of the surrounding quartz there was a reduction of volume which left spaces favorable for the deposition of pyrite and that this is the principal cause of the association. This harmonizes well with the fact that pyrite occupies fractures not connected with graphite, and that it is abundant in many of the non-graphitic rocks, such as the garnetiferous mica schists.

[19] See Siebenthal, C. E., "Zinc and Lead Deposits of the Joplin Region," U. S. Geol. Survey, Bull. 606, p. 62, 1915.

Whenever the blue rock is exposed in cuts or as waste on dumps, the pyrite rapidly breaks down, and, in protected nooks, a thick coating of white or greenish yellow iron sulphate (melanterite) accumulates in crusts and masses of needle-like crystals. Decomposition is so rapid that material on dumps may become comparatively soft and disintegrated within a year or two. The rapidity of decomposition suggests strongly that much of the ferrous sulphide may be present as marcasite rather than pyrite.

Graphitic Intrusive Matter.—Field observations on the occurrence of graphite in the injected matter were almost innumerable, yet it is impossible, owing to the erratic nature of the occurrences, to make any sweeping statement as to the relations observed. Conditions vary greatly in different mines, in the same mine, and even in the same vein. Both pegmatites and pure quartz veins may carry graphite in considerable quantity, occasionally, but rarely as much as in the surrounding ore. Both may also be entirely barren. In general the larger veins carry the least graphite. Those more than a foot thick seldom have any appreciable quantity.

Taking the area as a whole, perhaps 50 per cent. of the small veins in the ore cuts carry an appreciable quantity of graphite. In places it is disseminated irregularly throughout the vein. More commonly it appears to be concentrated rudely toward the borders. In very rare instances it seems to be concentrated in the center of the vein. Very frequently, though by no means always, the wall rock along the contact of the vein is notably enriched.

The size of flake, both in the veins and in the enriched wall rock, is much greater than in the normal ore, and flakes two to three millimeters in diameter are the rule rather than the exception. Rosettes, or radial growths of flakes, unknown in the normal ore, occur rarely in the veins. They are not of conspicuous size, however, as are reported in some other localities. Ordinarily, the flakes are arranged much more heterogeneously than in the schist, but even in the veins they may have a distinct orientation parallel to the walls.

The petroghaphic features of the graphitic veins are not unusual. Graphite in quartz, usually lies between, but also may cut through, the grains. In a section composed largely of badly strained and fratured quartz grains, graphite is abundant and occurs as irregular masses between grains, filling fractures in the grains, and cutting through the grains. Pyrite often accompanies the graphite and seems to be more abundant in feldspathic veins than in pure quartz veins. An unusual specimen from the Ceylon mine, Coosa County, consists principally of a mass of wollastonite in contact with quartz. Graphite is plentiful and occurs in three ways: (1) as long flakes between or cutting through quartz grains, (2) as short flakes strongly concentrated along the contact of quartz and wollastonite, (3) as short flakes and numerous irregular masses filling fractures and cleavage cracks in the wollastonite and accompanied by much pyrite. Pyrite is less abundant in the quartz, and there it fills fractures clearly later than the graphite.

In describing the hornblende schists it was asserted that they were entirely devoid of graphite. This statement is subject to the modification that very rarely the veins of intrusive matter cutting these schists carry traces of graphite, doubtless derived from the graphitic schists and transported into its present position.

In general, the writer accepts the common explanation of other geologists that the graphite in veins such as these represents carbon derived from the rocks which they intrude. He objects, however, to the usual loose statement that this graphite has been absorbed from the wall rock. Examination of the graphitic veins shows that the adjacent wall rock either is apparently unaffected by them or very often shows an actual notable enrichment in graphite flakes of unusually large size. This indicates that at the point of observation the vein was contributing carbon to, rather than abstracting it from, the wall rock. The presence of graphite in the vein is sufficient proof that conditions at the time it crystallized favored deposition rather than absorption of carbon. The absorption presumably took place at somewhat

greater depth, possibly much, possibly little, depending on the rate of upward movement during injection. Perhaps it was chiefly in the larger veins which now contain no graphite, in which case the smaller veins are the agents merely of transportation and deposition.

Commercially the graphite in the veins is of little value and their presence is generally detrimental, especially the quartz veins, which are difficult to mine and to crush.

Massive Graphite and Graphite Veins.—Graphite is found very rarely in small knots and bunches, practically pure. The writer noted masses an inch or more in diameter in a pegmatite vein, and a chunk six inches in diameter is said to have been taken from the Monitor mine north of Ashland. No true veins were found in the field, but Prouty[20] describes some. All are very small, generally a fraction of an inch thick and a few feet in length. They are of no commercial importance.

Graphite in Talladega Slate.—At many places the rocks of the Talladega series are highly carbonaceous, and amorphous graphite has long been known in the vicinity of Millerville. Prouty (p. 130) says the richest locality is about three miles southwest of Millerville on the road to Goodwater, where thin streaks of the rock contain 30 to 40 per cent. carbon.

The writer observed carbonaceous rocks of the same series in the fossiliferous area near Erin, and studied two thin sections of the rock. In hand specimens the rock is a gray to black, semicrystalline slate with very perfect but wavy and irregular slaty cleavage. It contains a good deal of pyrite, usually in small cubic crystals. The slate is very full of quartz veins ranging from six inches in thickness down to microscopic size, injected parallel to the cleavage. The veins pinch and swell rapidly, and many are little more than knots or oval lumps.

The only thing clearly distinguishable in the thin sections is the little veins and eyes of quartz. The rest of the rock is black and opaque and seems to consist mainly of submicroscopic quartz, minute sericite flakes and dark, carbonaceous matter. This has

[20] Prouty, W. F., *op. cit.* See p. 107.

a metallic luster in reflected light and is concentrated at many places into dark shiny lumps or streaks, frequently along shear zones or little folds in the rock. There is nothing approaching flake graphite.

Origin of the Graphite.—In this paper it is not proposed to treat exhaustively the origin of graphite, a difficult problem of much scientific interest, over which there has been an animated controversy, but a matter not of great practical importance so far as the Alabama deposits are concerned.

The general geological features of the region indicate clearly that the graphitic leads are lenticular beds in a series of metamorphosed sedimentary rocks. The mineralogical and chemical composition of the ores require that the original beds must have been very siliceous, probably rather pure sandstones with some clay and micaeous impurities. The carbon must have been an integral part of the formation at the time it was converted to graphite, as proved by the fact that it is restricted to certain limited beds of very definite lithology. It probably is impossible to determine whether this carbon was deposited with the sand as carbonaceous matter or whether it was in bituminous form and possibly was introduced from without as in the present-day oil sands. Either source might serve very well.

The graphite which is in the veins of quartz and pegmatite evidently was derived from carbonaceous or bituminous beds probably at no great distance from its present situation, presumably through some method of magmatic absorption. If this were not true, it should occur in equal abundance in those veins which cut the non-graphitic formations, which is quite contrary to all observations. Graphite is seldom seen in veins outside the graphitic schists and then usually in very small quantity and generally in close proximity to the graphitic rocks.

It is hard to evaluate the relative importance of plain dynamic metamorphism and of igneous injection in converting the carbon into graphite. The absence of graphite in so many veins and the lack of any of those features usually designated as "contact metamorphism" anywhere in the field led the writer to suspect at

first that injection was of little importance, although admittedly the graphite flakes within the veins average much larger than in the normal ore, and the size of flake at some places is much greater in a narrow zone at the vein walls. Study of the thin sections, however, shows that injection has been practically universal and that the microscopic veinlets also play an important part in increasing the size of graphite flakes, although the admixture of foreign matter doubtless lessens rather than increases the total carbon content. It seems necessary, therefore, to assign to the intrusive matter an important rôle in the development of large graphite flakes and it is rather probable that the conditions of great chemical activity and mobility which permitted such extensive injection also assisted greatly in the process of converting amorphous carbon into graphite. The condition of the carbon in the sections of Talladega slate may perhaps be construed as arguing either for or against this hypothesis. The slate is much less metamorphosed than the graphitic schists of the Ashland series but is injected freely. The injection, however, has been by quartz alone, and evidently represents a stage either later in the magmatic process or, more likely, farther removed from the magma and presumably much less intense in activity. Altogether a combination of strong metamorphosing forces and the high temperature and chemical activity accompanying very active injection seems to have been most favorable for the production of good graphite.

Troublesome Impurities in the Flake.—In refining Alabama graphite for use in crucibles, it is necessary to preserve the flake in the largest possible size and yet obtain a product that will run at least 85 per cent., preferably above 90 per cent., graphitic carbon. For lubricants it is desirable to remove the last trace of quartz because of its abrasive action. Unfortunately the graphite flakes often contain impurities both tightly attached and included between different lamellae of the same flake or between attached flakes, as when graphite and mica are interleaved. The included impurities seem to be chiefly mica and quartz.[21] To remove these

[21] Dub and Moses, *op. cit.*, p. 69.

impurities the concentrates from flotation or other processes generally are ground between buhr stones and then passed through air settling chambers and screens. The grinding is destructive of the flakes, but seemingly cannot be avoided.

Examination of samples of the finished product under the microscope shows that it contains a small amount of several different kinds of impurities. These include loose grains of quartz, pieces of mica, and fragments of other minerals, such as sillimanite. There are also rather numerous pieces of a white or semi-transparent isotropic material usually tightly attached to the surfaces of flakes. It may be stained brown or yellow by iron oxide. This may possibly be secondary silica, which might be present in oxidized ore. This is much more abundant in a sample of concentrates that has not been through the grinding process, which therefore seems to be effective in removing this type of impurity. Treatment of the attached films with hydrochloric acid and other common reagents generally had little effect upon them, although sometimes it tended to loosen the scale.

In the unoxidized blue rock, pyrite is an objectionable impurity, for sulphur is undesirable in crucible material. The intricate fashion in which it is often attached to the graphite makes it difficult to separate.

PRACTICAL APPLICATIONS OF THE STUDY.

Since the stratigraphy of the region has been so imperfectly understood, the probable ore-bearing acreage generally has been greatly overestimated. The detailed mapping shows that about one third the total rock section in the graphitic belt consists of hornblende schists, which are entirely barren. Fully two thirds of the remainder consists of garnetiferous and micaceous schists containing only a mineralogical trace of graphite. The remaining 10 to 20 per cent. of the acreage may deserve prospecting.

The broader structural features are important. In developing any locality it would be well to pick out a few distinctive markers, such as the hornblende schists, and, if possible, trace them for a considerable distance. They will generally show whether or not the area is complexly folded and faulted. Conditions for

mining are most favorable where the structure is least complex. The area shown in Fig. 1 seems to be rather more favorable in this respect than much of the other territory, though doubtless other areas of equally simple structure might be found.

Between graphitic schist, even of promising appearance, and possible ore, there may be a vast difference. Good ore must be rich in large flake, *which can be separated from its associated impurities*. The constant association of pyrite with graphite has thus far hindred working of the blue rock, but methods could be devised to overcome this difficulty, if the demand for graphite should warrant it. The rapidity with which the pyrite oxidizes when exposed seems to justify the suggestion that mere dump-weathering for a reasonable length of time might make the ore much more susceptible of treatment.

It seems probable that flake of commercial size is restricted closely to masses which have undergone very thorough and uniform injection by the quartz-rich magmatic juices. Since injection is by nature an uneven, erratic process, the best ore bodies are thereby greatly limited in extent. Within short distances the injected matter may drop so low that its improving influence is of no consequence, or the amount of vein matter may increase until the ore becomes unworkable.

One aspect of the situation that seems scarcely to have been considered at all is the fact that ore of good appearance and high carbon content may be worthless because of the physical nature of the graphite. If the flakes are small, if much of the carbon occurs as included matter in the sericite, if there has been subsequent movement with damaging effects to the flake, the ore may be worthless even though the chemical analysis is favorable. Much more attention should be paid to microscopic study of the ore. This combined with the present trenching methods, and perhaps with diamond drilling, would aid greatly in blocking out desirable ore, particularly if conditions should ever favor the mining of the blue rock, which seems to be the only hopeful source for any large or lasting industry.

COLUMBIA UNIVERSITY,
NEW YORK CITY.

RELATION BETWEEN ISOCARBS AND OIL AND GAS PRODUCTION IN KENTUCKY.

WILLIAM L. RUSSELL.

THE relation between the regional alteration of coals, as expressed by the isocarbs, and oil and gas production has proved to be of such importance in locating oil and gas pools that any further data bearing on this subject should be of interest. A study of this problem in Kentucky throws light not only on the favorable areas for future testing in that state, but also on certain aspects of the theory which may be of general importance.

The preparation of an isocarb map for Kentucky is beset with unusual difficulties. Besides the trouble encountered in trying to locate the analyses on the maps, it was found that the percentages of fixed carbon in the coal analyses differed enormously within a few miles or even a few feet. The cannel coals average about 10 per cent. lower in fixed carbon than the bituminous coals, and even among the bituminous coals there are wide differences between analyses from the same locality. Moreover, the averages of analyses of different reports on the same locality do not agree, and the analyses of the Kentucky Geological Survey run considerably higher in fixed carbon than those of the United States Bureau of Mines.

It appears that wide differences in the amounts of fixed carbon in the coals are caused by changes in their chemical character. Such differences have no relation to the structure or the regional alteration of the sediments and hence they should be eliminated as far as possible in making an isocarb map. The most important chemical factor affecting the amount of fixed carbon seems to be the proportion of canneloid and bituminous or woody material in them.[1]

[1] Thiessen, Reinhardt, "Structure in Paleozoic Bituminous Coals," U. S. Bureau of Mines Bull. 117, 1920.

The ordinary bituminous coals were formed in swamps, and are composed chiefly of woody fibres and similar materials. The cannels, on the other hand, were formed in lakes and other bodies of water, and are composed chiefly of the remains of spores, pollen, and the like. Of course all gradations between these two types occur, and furthermore the bituminous coals contain some canneloid matter, the amount of which varies irregularly. Moreover, in some beds small seams of cannel coal are interbedded with the bituminous matter.

The cannel coals run higher in volatile matter and lower in fixed carbon than the bituminous coals, as is well known. Though the percentage of fixed carbon (moisture and ash free) averages roughly 10 per cent. lower in the cannels, the actual amounts vary greatly, ranging from a few per cent., to 20 per cent. lower. It does not appear possible in this region to obtain the regional fixed carbon content of the bituminous coals by adding any definite amount to that of the cannel coals. About all that can be said is that the average fixed carbon content of the bituminous coals is much higher.

The previous articles on the subject do not emphasize sufficiently that cannel coals should not be used in preparing isocarb maps. If the analyses of the cannel coals were used the maps would tend to show areas of low fixed carbon content in the regions where there was much cannel coal. As these areas would not indicate regions of low regional alteration, they would greatly detract from the value of the map. In fact, a map prepared in this way might lead one to believe that certain regions in which the carbon ratios were really too high for oil and gas were altered merely to the ideal degree, and such a map would be worse than nothing. Some of the previous articles give one the impression that an isocarb map may be made by setting down the analyses and drawing the isocarbs around them, as contours are drawn in making a structure contour map. Any attempt to use this method in the Eastern Coal Field of Kentucky would result in hopeless confusion, owing to the great variation in the amounts of fixed carbon in the analyses of the bituminous coals. Even

if the isocarbs could be drawn they would merely show the variations in chemical characters of the coals, and would not be indicative of the regional alteration of the sediments. In order to draw the isocarbs it was found necessary to average the analyses for each district. These regional averages agree with each other quite closely and their variations appear to be determined chiefly by the regional alteration of the strata.

One peculiar feature, already mentioned, is that the analyses of the Kentucky State Geological Survey average higher in fixed carbon than those of the United States Bureau of Mines. This occurs in so many cases that it can scarcely be due to chance. The difference between the two sets of analyses for certain counties is shown by the following table:

TABLE I.

County.	Analysts.	Number of Analyses.	Average per cent of Fixed Carbon, (Moisture and Ash Free).
Bell.....	U. S. Bureau of Mines	123	59.6
Bell.....	Ky. Geol. Surv.	70	63.2
Harlan.....	U. S. Bureau of Mines	111	60.0
Harlan.....	Ky. Geol. Surv.	110	62.3
Knox.....	U. S. Bureau of Mines	15	59.6
Knox.....	Ky. Geol. Surv.	10	62.1
Letcher.....	U. S. Bureau of Mines	29	60.8
Letcher.....	Ky. Geol. Surv.	64	61.8
Perry.....	U. S. Bureau of Mines	35	60.1
Perry.....	Ky. Geol. Surv.	36	61.9

A complete map could not be made from the United States Bureau of Mines' analyses alone, as the area in which they were sufficiently abundant is restricted to a few of the large mining areas.

The isocarb map shown in Fig. 1, is based on over 2,100 analyses, which were obtained from the publications of the United States Geological Survey, the United States Bureau of Mines and the Kentucky State Geological Survey. These were reduced

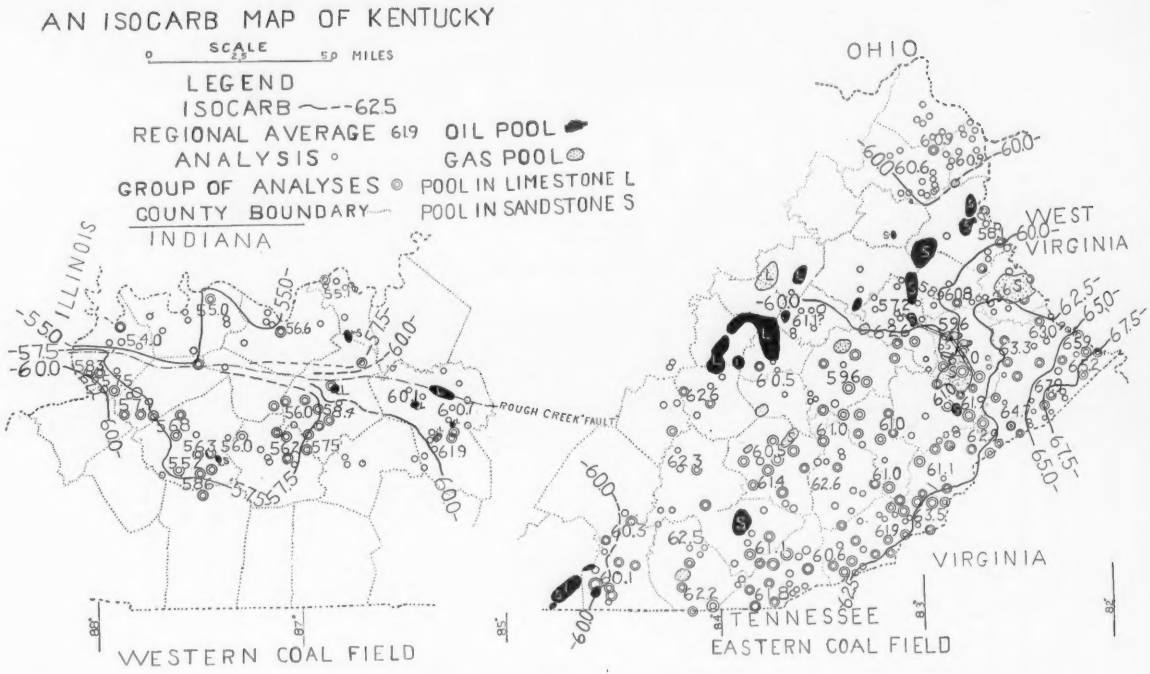


FIG. 1. An isocarb map of Kentucky.

to a moisture and ash free basis, and the isocarbs are drawn upon the basis of the regional averages, exclusive of the cannel coals.

Considering the difficulties and uncertainties encountered in making an isocarb map in this area, the relation of the isocarbs to the oil and gas pools is astonishingly good.

Nearly all of the good oil and gas production from sandstones and most of that from limestones lies below the 60 per cent. isocarb. The gas pools are for the most part located between the 60 per cent. and 62.5 per cent. isocarbs. Moreover, in the case of most of the oil pools in sandstones above 60 per cent., the ratio of gas to oil is much greater than in the case of the oil pools in sandstones below the 60 per cent. isocarb. In the pools above 60 per cent., the production is quite "spotted," owing to the irregular porosity of the sandstones. Production in these pools consists for the most part in small oil wells scattered among gas wells and dry holes. The area in the extreme eastern part of the state, where the coals have a fixed carbon content greater than 62.5 per cent. is barren of oil and gas, as yet. In the Western Coal Field of Kentucky the amounts of fixed carbon in the analyses, especially those of Coal No. 9, are not so variable as they are in the Eastern Coal Field, and, with the exception of Breckenridge county, there are not so many cannel coals to cause confusion. In the Eastern Coal Field the best oil pools in sandstones are in the area below 60 per cent. An area of relatively strong faulting, steep folding and general anticlinal structure known as the Rough Creek Fault runs across the Western Coal Field in an east-west direction. The fixed carbon percentage of the coals in the eastern part of this fault zone are above 60 per cent. Sandstones along this Rough Creek Anticline frequently contain oil, but owing to the alteration of the rocks the Mississippian Sandstones are generally of too low porosity to produce oil in commercial quantities.

It is noteworthy that in Kentucky, as elsewhere,[2] the coals are higher in fixed carbon in the anticlines than in the synclines. Part of the area in the Eastern Coal Field which is below 60 per

[2] White, David, "Some Relations in Origin between Coal and Petroleum," *Journal of Washington Acad. of Sci.*, pp. 189–212, 1915.

cent. lies close to the regional syncline, and in the Western Coal Field the coals are lower in fixed carbon in the two synclines north and south of the Rough Creek "Fault" than they are in the anticline between them. Possibly this relation is due to more pronounced deformation in the anticlines, or to the fact that older rocks are exposed in them.

One of the most interesting features of the isocarb map is the suggestion that oil and gas pools may occur in limestones where the regional alteration of the rocks is too high for their occurrence in sandstones. In other words, the regional alteration of the rocks may be less effective in destroying the pools in limestones than those in sandstones. The features which suggest this are as follows:

1. The oil pools in the limestones tend to occur in areas of higher fixed carbon content than those in sandstones, as shown by the isocarb map.

2. Although it is well known that, in general, the alteration of the sediments increases with age, the oil pools in limestones occur in older rocks than those in sandstones. Most of the oil and gas production from limestones is chiefly from the Devonian, and partly from Ordovician rocks.

3. In Wayne and McCreary counties, where the fixed carbon content of the coals is about 60 per cent., production is found in Ordovician limestones.

4. In the eastern part of the Western Coal Field, where the fixed carbon content of the coals is well over 60 per cent., oil and gas pools occur in limestones of Ordovician and Devonian age, though the Mississippian sandstones in that region are generally hard and barren of oil in commercial quantities.

5. In Elliot county, a group of steep anticlines with large closures occurs associated with the Newcombe Creek Fault. The Berea and Weir sandstones, of Mississippian age, on these steep anticlines are for the most part hard and tight and contain only shows of gas and oil. The Corniferous limestone, of Devonian age, is, however, quite generally porous. Wells drilled to it in the synclines yield small amounts of salt water, while those on the anticlines make small gas wells.

6. In Floyd county where the Pennsylvanian coals contain close to 60 per cent. of fixed carbon and in the southern part well over 60 per cent. fixed carbon, the Mississippian and Pennsylvanian sandstones are for the most part hard and tight, with porous pockets or lenses from which gas, salt water and oil are produced. The Devonian Corniferous limestone which is much deeper and much older is also porous, in places, and oil and gas have been found in it. (See Fig. 2.)

While the isocarb map has an important use in predicting the best areas for testing, it should be understood that it merely gives an indication of one of the conditions necessary for the occurrence of oil and gas. If source rocks and porous reservoirs are not present, there will of course be no production, no matter how ideal the isocarbs are. On the other hand, if the isocarbs are extremely unfavorable, there should be no oil or gas production, even though the other favoring conditions are present.

In Pike county, especially in the eastern part, the isocarbs are much too high, being generally over 62.5, and in places over 67.5. Although in this region there are good looking structures, thick source rocks, and sandstones associated with them, it may be considered a highly unfavorable place for testing. Most of the Eastern Coal Field is between the 60 per cent. and 62.5 per cent. isocarbs. This area may be considered possible gas territory, where the other conditions are favorable. In the area along the Rough Creek " Fault " of the Western coal field, where the fixed carbon content is close to 60 per cent., the conditions are rather unfavorable for finding oil in commercial quantities in the sandstones of the Chester group, for these are generally hard and tight. However, if it is true that oil pools occur in limestones in areas where the sandstones are too much altered to produce oil, then it is possible that oil pools will be opened up in these areas by deeper drilling to the Corniferous and Ordovician limestones.

According to Fuller [3] the chances for obtaining oil increase to-

[3] Fuller, Myron L., " Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," ECON. GEOLOGY, vol. 14, No. 7, pp. 536–542, 1919. " Carbon Ratios in Carboniferous Coals of Oklahoma, and their Relation to Petroleum," ECON. GEOLOGY, vol. 15, No. 3, pp. 225–235, 1920.

ward areas of low carbonization, and are best when the fixed carbon content is slightly less than 55. The Western Coal Field is, in general, much lower in fixed carbon content than the Eastern, most of it being below 60. This region is underlain by 100 to 400 feet of black or brown Devonian shale which would make a good source rock. Sandstones of the Pennsylvanian and upper Mississippian age would make good reservoir rocks. Numerous small steep anticlines generally associated with faults exist in this region. The best reservoir rocks are separated from the black Devonian shales by 800 feet or more of strata, chiefly limestones; but the faults may permit the migration of the oil to the reservoir rocks. It appears to the writer that the chances are good for discovering new oil pools in his area. South of the Rough Creek "Fault" the folds are steeper and the fixed carbon content of the coals higher than they are to the north of it. To the north of the fault in the northwestern corner of Kentucky there is an area in which the fixed carbon content is below 55 per cent., as shown by the map. From the standpoint of the carbon ratios alone, this is the most promising part in Kentucky. Untested structures are found in this region also.

Besides throwing light on the best areas for testing, the regional alteration of the coals is related to two theoretical problems of considerable interest. One of these is the absence of water in certain sandstones. The absence of water in sandstones encountered in deep mines and wells has been thought by some to be due to their depth, but Fuller[3] has shown that the lack of water is related to the regional alteration of the rocks. Water has been found in California at a depth of over 6,000 feet. It seems to the writer that the absence of water may be due to three causes:

1. The sands may have been dried out in an arid climate and been buried without water.

2. The sandstones may have been of too low porosity to yield water in appreciable quantities.

3. The volume of oil and gas entering the sandstone may have been sufficient to displace all or nearly all of the original water content. This applies to both sandstones and porous limestones.

Examples of the last two cases occur in the area under consideration. Sandstones in Floyd and Pike counties, especially the latter, are frequently found to have no appreciable quantities of any fluid, owing to their low porosity. An example of the third type is the Corniferous limestone in Magoffin and Floyd counties, which contains oil and gas, but with little or no salt water. This appears to some extent in the section in Fig. 2. The Berea Sandstone in West Virginia to the east of the area covered by the map, may be another example. In fact this condition seems to be quite common in the Appalachian Oil Field. As is to be expected, "sands" of the third type tend to occur in association with thick beds of source rocks, and in areas where the regional alteration has been quite intense, so that much of the organic matter has been altered to oil.

The regional alteration of the sediments is also related to the question of the migration of the oil and gas. According to the hydraulic theory of oil and gas accumulation, water enters the oil "sands" at their southeastern outcrop where they are higher, and flows under artesian head through the sands across the basin, issuing from a supposed outcrop on the northwestern side. It is obvious that according to this theory the water must have an open and continuously porous medium all the way across the syncline. An examination of the regional alteration of sediments shows pretty conclusively that this does not exist, for the oil "sands" become hard and tight before they rise to the surface towards the southeast. In the southeastern part of Kentucky and southeast of that this may not be true, as the carbon ratios are not much over 60 per cent., but here artesian circulation would be blocked by the Pine Mountain Thrust Fault.

The section shown in Fig. 2, represents the subsurface conditions along a section from southern Magoffin county southeast into Floyd county. The line of the section is shown on the map by a double line. The fixed carbon content of the coal is in general below 60 per cent. in the northwestern half of the section, and above 60 per cent. in the southeastern half. It is introduced because it is typical of conditions in the eastern fields, and brings

out more definitely some of the general features which have been discussed.

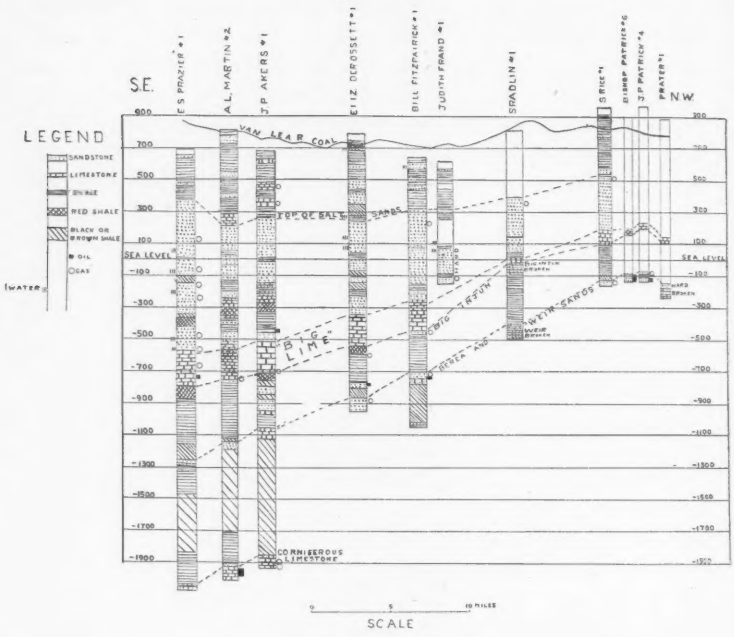


FIG. 2.

Section in Floyd and Magoffin Counties, Ky. Published by Permission of the Bed Rock Petroleum Co., and the Midsouth Oil Co.

The surface structure is shown by the line representing the Van Lear Coal, which was plotted from the maps of the Kentucky Geological Survey. The subsurface structure is best shown by the "Big Lime." The lack of conformity between the two is very striking. In its northwest part the section crosses an oil and gas pool. There is here an anticline in the surface rocks, and as Jillson has stated [4] the subsurface structure indicates that

[4] Jillson, W. R., "A Mauch Chunk Island in the Mississippian Seas of Eastern Kentucky," Economic Papers on Kentucky Geology, Kentucky State Geological Survey Series VI., pp. 227–232, 1921.

the fold began before the coal was laid down, as shown by the section.

One of the most striking features of the section is the lenticularity and irregularity of the sands. Production is obtained in part from a thick series of sandstones in the base of the Pennsylvanian, known as the "Salt Sands." The top, the bottom and the position of the breaks in these sands are all very irregular, and differ greatly from well to well. Just above the "Big Lime" is another sand, called the Maxon or Bradley. This sand is also rather lenticular, while the Big Injun below the "Big Lime" is highly irregular and patchy. The sandstones below the Big Lime are generally logged as "Weir," though sometimes as "Berea." These sands are quite regular to the north and northwest, but become patchy and limey in the southeastern part of the section.

The effect of the regional alteration on the porosity of the sands is indicated by the occurrence of sandstones of considerable thickness without salt water, oil, or gas. In some cases, especially in the northwestern part of the section, this is due to failure to log the salt water, but in many cases the sandstones are undoubtedly without any appreciable content. The pockets of porous sandstone in which the oil and gas occur are highly irregular. Wells yielding only shows of oil and gas sometimes are drilled only one location away from wells producing over a million cubic feet per day.

Many of the important oil "sands" of the Pennsylvania, New York and West Virginia oil fields pinch towards the northwest, and become hard and impervious to the east, owing to the regional alteration of the rocks. Either of these conditions would be enough to prevent artesian circulation. The great group of oil "sands" of upper Devonian age pinch completely before they come to the surface in northeastern Ohio, and the same is true of most of the Mississippian "sands," with the exception of the Berea. The Sharon conglomerate or "Salt Sand" is also patchy or absent in most of eastern Ohio. Thus it seems that most of the oil sands of this field become impervious on at least one and generally both sides of the productive belt. Under these condi-

tions any interior circulation strong enough to effect oil migration is not likely.

CONCLUSIONS.

1. In certain regions, such as the Eastern Coal Field of Kentucky, where the amounts of fixed carbon in the coals vary greatly, regional averages rather than single analyses must be used in making isocarb maps.

2. Cannel coals and semi-cannel coals should not be considered in making these maps.

3. Certain features suggest that oil may be found in limestones in regions of higher fixed carbon content or regional alteration than it is found in sandstones.

4. Analyses of the Kentucky State Geological Survey appear to average higher than those of the United States Bureau of Mines.

5. In Kentucky there is a marked relation between the isocarbs and oil and gas production and the porosity of the sandstones.

6. From the standpoint of the isocarbs alone, the best place for future testing is the portions of the Western Coal Field which are well below 60 per cent.

7. Owing to the high regional alteration of the rocks in areas adjoining most of the Appalachian Oil Field artesian articulation would be prevented in many of the oil "sands."

YALE UNIVERSITY,
NEW HAVEN, CONN.

A SULPHIDE DIABASE FROM COOK COUNTY, MINNESOTA.[1]

G. M. SCHWARTZ.

Introduction.—While engaged in field work for the Minnesota Geological Survey during the summer of 1923, the writer examined a test pit located in Cook County,[2] Minnesota. Considerable material was collected and studied in the laboratory. The occurrence of diopside and the rare mineral xonotlite in this deposit has been recently described.[3] Further studies have shown that the diabase from this pit contains sulphides which are apparently primary and enclose feldspars like the augite of the diabase. The deposit was revisited the past summer and the field occurrence reviewed and more material collected. So far as known an occurrence of this sort has not been previously reported.

The writer is indebted to Prof. A. F. Buddington of Princeton University for suggestions regarding the nickel minerals, to Mr. Melvin Green of Mineral Center for much help in the field, and to Dr. F. F. Grout for suggestions and criticism.

Occurrence.—The general geologic relations of the area are shown elsewhere.[4] The deposit is located in an area of Animikie slates and graywackes with many Keweenawan intrusives, principally large dikes and sills of diabase, but rarely of other types.

The test pit followed vertical fractures and replacement veins in a diabase dike near the contact with slate. Specks of sulphides may be seen disseminated through the diabase, but along the fractures are masses consisting principally of sulphides with residual

[1] Published by permission of the Director of the Minnesota Geological Survey.

[2] The SW¼, SE¼ Sec. 35, T. 64 N., R. 5 E.

[3] Schwartz, G. M., "An Occurrence of Xonotlite in Minnesota," *American Mineralogist*, vol. 9, pp. 32–33, 1924.

[4] Pigeon Point Plate (No. 85), Volume 6 of the Final Report of the Minnesota Geological and Natural History Survey.

fragments of diabase, much of the original rock having been replaced by sulphides. The sulphides are most extensive where fractures intersect and include at places, masses of xonotlite ($5CaO, 5SiO_2 \cdot H_2O$) and diopside. These masses usually consist of several rounded lumps or nodules of xonotlite with a border of diopside. The manner in which the silicates are embedded in the sulphides indicates that they were deposited at the time the vein was formed. The sulphides in the diabase are not confined to the deposit at this particular pit, but are found at places over an area of several square miles. They are apparently near the contact of diabase and slate, but have not been found directly at the contact or in the slate. Xonotlite has been observed in this region only in the test pit noted above.

Microscopic Features.—A study of thin sections and polished surfaces of the wall rock near the fractures, and of sulphides and fragments of diabase found in the fractured zone reveals a remarkable contrast between the material of the two locations.

Thin sections of the rock a foot and more from the vein show a well developed diabasic texture. (See Plate I., *A* and *C*.) The essential minerals are: plagioclase (labradorite), olivine, and augite, with accessory pyrrhotite, chalcopyrite, magnetite, and biotite. The only alteration products are small amounts of serpentine in cracks in olivine, and an occasional grain of chlorite. Plagioclase makes up from 50 to 60 per cent. of the diabase and occurs as euhedral crystals apparently free from alteration products of any kind. Olivine, augite, magnetite, and the sulphides fill in around the lath-shaped feldspars. (See Plate I., *A* and *C*.) Magnetite is small in amount and in some cases is intergrown with the sulphides which are somewhat more abundant than magnetite.

There are no minerals which might represent a late magmatic stage of alteration and introduction of sulphides as recently described by Kerr [5] for a magmatic ore of copper and nickel from Chicagof Island, Alaska.

[5] Kerr, Paul F., "A Magmatic Sulphide Ore from Chicagof Island, Alaska," ECON. GEOL., vol. 19, pp. 369–376, 1924.

An examination of polished surfaces of the diabase shows that the sulphides in the diabase consist of pyrrhotite and chalcopyrite with the former predominating. The sulphides obviously crystallized later than the feldspar as shown by their matrical position and occasional stringers cutting feldspar crystals. There is, however, a lack of evidence that the sulphides replace the silicates but on the contrary it is strongly indicated by the relations described that the sulphides crystallized as rock minerals, doubtless nearly contemporaneous with magnetite. On this basis the rock is classified as a *sulphide diabase.*

The residual fragments of diabase found with the massive sulphides in the vein are in marked contrast to that described above. Olivine and augite have largely disappeared, but occasionally remain showing the original texture of the rock. For the most part the rock is intensely altered and though plagioclase remains as an abundant constituent, it has lost its euhedral form and is filled with alteration products. Chlorite, serpentine, secondary, biotite, quartz, sericite, magnetite, and sulphides are more or less abundant, especially serpentine. (See Plate I., *B.*) In places a large grain of augite may be seen partly altered to a mixture of biotite, magnetite, and quartz. Many veinlets contain cross-fibers of serpentine indicating the incipient development of chrysotile asbestos. In the available thin sections of the altered rock the sulphides vary from small amounts to fifty per cent. or more. It is obvious that the sulphides in the veins were, for the most part, introduced during a perod of hydrothermal alteration and replaced the minerals of the diabase. Rarely areas of sulphides are found which have the sharp straight boundaries of the original diabase, as in the rock far from fractures. These indicate two generations of sulphides. The first generation is believed to have been of true magmatic origin and the second introduced by the hydrothermal solutions connected with the intrusive and probably closely following the solidification of the diabase.

A study of polished surfaces shows that pyrrhotite and chalcopyrite with subordinate amounts of pentlandite and a mineral

resembling polydmite make up most of the sulphides. A few grains of a white mineral of medium hardness were found in various specimens, but these did not react like any mineral in the mineralographic tables and the grains were too small to permit an identification by blowpipe methods. Chalcopyrite and pyrrhotite are about equally abundant but in some specimens, the latter predominates. As a rule, they have mutual irregular boundaries but in some places blades of pyrrhotite cut the chalcopyrite or the two minerals are intergrown as laths and blades as shown in Plate I., *D*. This texture is practically identical with that recently figured by the writer [6] for chalmersite and chalcopyrite at Fierro, New Mexico, and Parry Sound, Ontario. These relationships point to a more or less contemporary deposition of pyrrhotite and chalcopyrite. However, in some specimens the chalcopyrite apparently embays and surrounds the pyrrhotite or cuts it as stringers and follows the boundaries of the pyrrhotite and other minerals, all indicating a late crystallization of part of the chalcopyrite. Pentlandite occurs as scattered grains and areas in the other sulphides. Some of the grains are corroded only around the outside, but most of them have been penetrated along the cleavage by chalcopyrite and pyrrhotite and in some cases these minerals have largely replaced parts of the pentlandite areas. It is obvious that pentlandite crystallized somewhat earlier than chalcopyrite and pyrrhotite.

The pentlandite is cut by a network of veinlets of a mineral with a violet color which the writer identified as polydmite by use of Davy and Farnum's tables. However, Professor Buddington examined some of the specimens and pointed out [7] that the mineral corresponded somewhat to the mineral Lindgren called violarite; also to bravoite. Since then Lindgren and Davy's paper [8] has appeared showing that the mineral used in compiling

[6] Schwartz, G. M., "Chalmersite at Fierro, New Mexico, with a Note on its Occurrence at Parry Sound, Ontario," ECON. GEOL., vol. 18, Plate X., *C* and *D*, 1923.

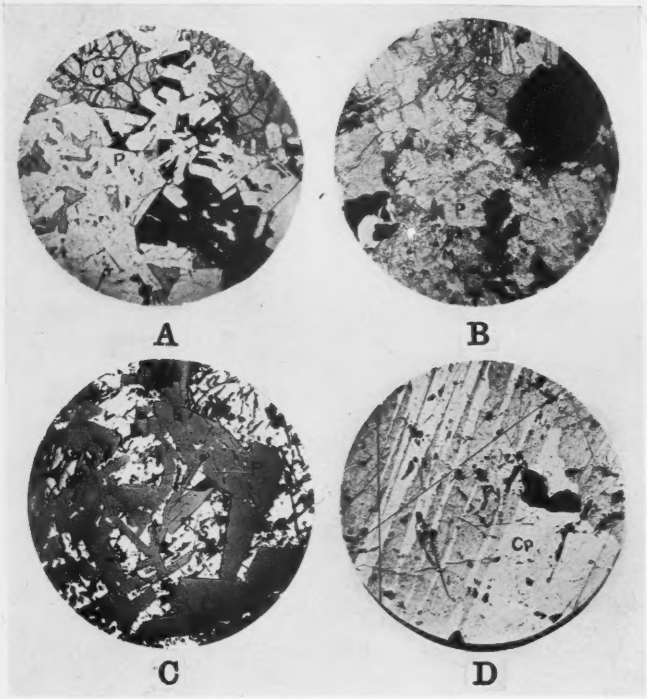
[7] Personal communication.

[8] Lindgren, W., and Davy, W. M., "Nickel Ore from the Key West Mine, Nevada," ECON. GEOL., vol. 19, pp. 309–319, 1924.

PLA

A
(*O*)
in s
B
the
(*P*)
Blac
C
plag
crys
ing
D
Sho
text

MAY 5 1925



A. Micrograph of a thin section of a sulphide diabase. Note fresh olivine (*O*), augite (*A*), and plagioclase (*P*). Euhedral feldspar crystals are embedded in sulphides (black).

B. Micrograph of a thin section of altered diabase from sulphide vein. Note the highly altered character-Serpentine (*S*) has replaced olivine, the plagioclase (*P*) has largely lost its euhedral form and is filled with alteration products. Black is sulphides except for magnetite specks (*M*). Contrast with (*A*).

C. Micrograph of a polished surface of a sulphide diabase. Note the euhedral plagioclase (*P*) grains with perfectly sharp borders, embedded in sulphides. Late crystallization of the sulphide (*S*) is shown by a small veinlet of sulphide crossing a feldspar grain.

D. Micrograph of a polished surface of massive sulphide ore from the vein. Shows a bladed intergrowth of pyrrhotite (*Py*) and chalcopyrite (*Cp*). The texture is believed to indicate contemporaneous deposition.

the tables was not the original polydmite from Grünau and that the minerals used differed in certain respects. This led Professor Lindgren to suggest the name violarite for the violet-colored nickel mineral resembling polydmite which is found at Sudbury and at the Key West mine, Nevada. The formula provisionally assigned is NiS_2. In so far as the small amounts available allow determination, the mineral in the Minnesota material agrees with Lindgren's tests and its occurrence is much like that at the Key West mine and strongly suggestive of supergene action. However, Professor Buddington has shown [9] that violarite is so similar to bravoite [$(NiFe)S_2$] that the two may not be distinguished with certainty although he is inclined to believe that the secondary mineral such as found in the ores described here more nearly corresponds to bravoite. Unfortunately little can be added to help solve this interesting problem as the mineral is not abundant enough to permit a detailed examination or analysis.

The presence of nickel minerals in the ore was checked by the following partial analysis of rich sulphide material from the vein. The writer is indebted to the Minnesota Mines Experiment Station for the analysis.

Fe, 32.63 per cent.; Cu, 18.26 per cent.; Ni, 0.52 per cent.; S, 26.21 per cent.

Magnetite was seen only rarely in the polished ore except in the diabase fragments The few occurrences noted were as rounded or subhedral grains embedded in sulphides and apparently earlier in crystallization.

The order of the minerals in the vein apparently is: magnetite, pentlandite, pyrrhotite and chalcopyrite, chalcopyrite, with a supergene nickel mineral, resembling violarite and bravoite, replacing pentlandite.

[9] Buddington, A. F., "Alaskan Nickel Minerals," ECON. GEOL., vol. 19, pp. 521–541, 1924. See Hildebrand, W. F., *Am. Jour. Sci.*, ser. 4, vol. XXIV., p. 151, 1907.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

PHOSPHATE DEPOSITS OF THE PACIFIC.

F. DANVERS POWER.

INTRODUCTION.

SPEAKING in a general way, guano may be looked on as a deposit of excreta from birds—mostly sea-fowl—and on a smaller scale from bats, with which bones are associated as accessories. The guano may have been recently deposited, when, besides phosphates, it is rich in nitrogenous matter; but fresh guano is easily acted on by the weather. In rainless districts, *e.g.*, at Mejillones on the Chilian coast, which formerly belonged to Bolivia, the heat of the sun has evaporated the ammonia. On islands where rain and spray reach the deposit, ammonia and the soluble di-basic phosphate are leached out, leaving a residue which is not worth shipping. Guano is suitable for direct application to the soil.

Phosphate rock was originally a limestone, or dolomite, but has had its carbon dioxide replaced by the stronger phosphoric acid. The soluble di-basic phosphate, leached out of the guano, has drained down to the underlying rock and taken up sufficient lime to form the less soluble tri-basic phosphate. The original limestone of these guano islands was coral rock composed mostly of aragonite, which is more readily attacked than calcite as it is less stable.

Of course there are progressive stages between guano and phosphate rock, when it may be convenient to call the deposit guano-phosphate. This intermediate product is rather inconvenient in the case of the New Caledonian mining law, which has certain regulations for guano, and others for phosphate rock.

DISTRIBUTION OF GUANO ISLANDS.

Most of the guano islands of the Pacific are within the tropics. Many of them have been worked in the past, but are now either

depleted, or too poor to be worked under existing conditions, *e.g.*, the Howland and Baker islands in the Central Pacific; islands of the Phœnix group; Laysan and Gardner islands in the Hawaiian Group; Raine, Bunker, and Lady Elliott islands off the North Queensland coast; and Washington, Fanning, Starbuck and Jarvis islands.

Guano islands being worked at the present day are Clipperton, belonging to Mexico; Pescadores, Guañape, and Chincha islands belonging to Peru; and Malden Island belonging to Great Britain, which has been worked for over sixty years.

Guano-phosphate has been worked on Surprise, Fabre, and Le Leizour islands of the Huon group, north of New Caledonia; and Walpole island, south of New Caledonia, both belonging to the French.

Rock phosphate is being mined at Raza island, belonging to the Japanese; Angaur island of the Pelew group, mandated to the Japanese; Makatea in the Paumotu group, belonging to the French, the head office of the company being at Tahiti; Ocean island belonging to the British, and Nauru, mandated to the British.

Christmas island in the Indian Ocean, belonging to the British, on which rock phosphate is mined, must not be confounded with Christmas island in the Pacific, which has never been worked for phosphate.

All the likely islands in the Pacific have been examined two or three times by different parties searching for phosphates, but without success. Apparently the only undiscovered phosphate one can hope for is a little recent guano deposited on islands unfrequented by man.

A small quantity of guano is obtained from islands off the coast of Western Australia, but as these are in the Indian Ocean, they do not concern this paper.

AUSTRALIA.

The largest deposits of rock phosphate so far discovered in Australia occur in South Australia. These are distributed inter-

mittingly along a belt of country some 200 miles long, from Myponge in the south, to the district around Carrieton in the north. The phosphate, which is white, yellow, and brown in color, occurs in gray clay, calcareous marl, and sandy clay in the form of nodules, and bed-like segregations: there is no regular stratification. These beds are associated with Cambrian limestones, quartzites, and sandstones. H. Y. L. Brown suggests [1] that the mud and sand deposits were formed at the bottom of the then existing sea, which was inhabited to a greater or less extent by forms of life which secreted phosphate of lime, just as the coral polyps secrete carbonate of lime, conditions being more favorable for one or the other at different periods. Selected ore of high grade—over 60 per cent. tri-calcic phosphate—is sent to the superphosphate plants of Wallaroo and Port Adelaide, but there is a larger tonnage of low-grade material which remains unused. From 1913 to 1922 there were mined 57,332 tons, but the quantity appears to be falling off, for they mined 8,753 tons in 1920, 5,079 tons in 1921, and only 2,715 tons in 1922.

The phosphate deposits of New South Wales [2] are all cave deposits, and with the exception of a little bat guano, used by local farmers, consist of limestone and bone breccia, the phosphate not penetrating far into the solid limestone. Attempts have been made to boom these cave deposits, but they never proved a commercial success. The Wellington caves, chiefly of interest as forming tombs for herbivorous and carnivorous marsupials, have only provided a limited amount of high-grade phosphate, and are no longer being worked. Caves in the neighborhood of Cowra provided 576 tons of phosphate in 1920. Some phosphate has also been won from the Ashford caves in the Inverell district.

In Queensland, a limited amount of low-grade guano, 50 per cent., has been mined on small islands off the coast.

[1] H. Y. L. Brown, "Notes on the Rock Phosphate Deposits of South Australia," *Proc. Aus. Ass. Adv. Sci.*, 1909, vol XII., p. 239.

[2] J. E. Carne, "Phosphate Deposits in Limestone Caves in New South Wales," Ann. Rept. Dept. of Mines, 1914, p. 191.

At Clarendon, on the South Island of New Zealand, a low-grade phosphate rock is mined.

PACIFIC ISLANDS.

The chief deposits of phosphate, however, are to be found on islands in the vast wilderness of the Pacific. Angaur island supplies the Japanese with about 30,000 tons of rock phosphate per annum; and Makatea produces some 39,000 tons for the French; but by far the greatest amount of rock phosphate is mined on Ocean and Pleasant islands, which are under the control of the British, and which are the largest and richest known deposits in the world. These two islands together produce about 400,000 tons per annum.

Pleasant Island—native name Nauru—was discovered by Captain Fearn of the *Hunter,* in the year 1789. It was called Pleasant island on account of the pleasant appearance of the natives; but when the Germans annexed it in 1888 they adopted the native name, by which it is now more generally known. It has an area of about 4,690 acres, including a small lagoon near the southwest corner, which has 5 feet of water and 2 feet of mud. The island is fringed with a shore reef, 100 to 130 yards wide, which is exposed at low water. No phosphate has been found below this level. On the shore side of this is the coconut belt, 30 to 440 yards wide and about 20 feet high: this is really a continuation of the shore reef covered with coral sand and debris thrown up by the waves. At the back of the coconut belt are cliffs 20 to 30 feet high, and on the high land are three main ridges, the higher points of which are about 210 feet above sea level. On the sea side of the shore reef, the island goes down at an angle of 45 degrees, which makes it impossible to secure a safe anchorage in bad weather. In September, 1914, soon after the outbreak of war, H. M. A. S. *Melbourne* captured the island from the Germans. At a later date, Nauru was mandated to Great Britain, Australia, and New Zealand. The price paid by these Governments, including the purchase of Ocean island, was £3,500,000. The proportion paid by these countries in the order

named was 42, 42, and 16 per cent., with the right to have the same proportion of the phosphate produced in any one year for home consumption, not for export, the basis of allotment to be adjusted every five years in accordance with the actual requirements of each country. Great Britain has not availed herself of her proportion, because of heavy freight charges.

Ocean Island—native name Banaba, meaning rocky island—was discovered in 1804, and was named after the ship in which the discoverers were sailing. It is situated 160 miles to the east of Nauru, the nearest land. It was proclaimed a British possession by Captain Tupper of H. M. S. *Pylades* in 1901. Its physical features are similar to Nauru, only there is no coconut belt. It has an area of about 1,390 acres, and the highest point is about 260 feet above the sea.

The past geological history of Nauru and Ocean island is that of all the guano and rock phosphate islands in the Pacific. It is not necessary here to enter into the question of the origin of coral islands, or the cause of their rising and sinking; suffice it that they have risen and sunk, and that in so doing have affected the formation of the phosphate deposits.

In the year 1897, the supercargo of the S. S. *Archer* picked up what seemed to him an unusual looking piece of rock on Nauru, and brought it to Sydney, where it was left at the office of his company till 1900, where it served to keep the door of the laboratory open. It was eventually tested and was found to be rock phosphate. This led to a search for further deposits, and a similar occurrence was found on Ocean Island. Originally it was estimated that there were forty-two million tons of phosphate on Nauru, and fourteen million tons on Ocean Island, but from work that has been done since, it is thought that there are not less than one hundred million tons on the two islands. Phosphate is worked from between pinnacles of rock for a depth of 40 feet at Nauru, up to 65 feet at Ocean island and there is still phosphate underfoot, but it does not pay to work under existing conditions when the space between the pinnacles becomes too narrow. Work on Ocean Island was commenced in 1900 and at Nauru in 1906.

(See Fig. 1.) The percentage of tri-basic phosphate is not only high but fairly uniform. For the past 22 years, the cargoes of phosphate have averaged between 85 per cent. and 88 per cent. tri-basic phosphate of lime.

FIG. 1. Pinnacles left on Nauru after the extraction of phosphate. (Courtesy of British Phosphate Commission.)

Before the advent of man, these islands were the camping and breeding grounds of numerous seafowl. Anybody who has had an opportunity of seeing bird islands can readily understand how deposits of guano are formed. The chief seafowl forming these rookeries are the sooty tern, the man-of-war hawk or frigate bird, mutton bird, pelican, boatswain bird, and gannet. The birds generally occupy low islands, sometimes not more than 10 or 12 feet above the ocean, and long before the land comes within range of vision, its position can be determined by the clouds of birds to be seen hovering above it. In places the birds build or form such nests as they think good enough for their offspring, so close together that it is almost impossible to find footroom between them. Different varieties of birds do not all nest at the same time of year, but seem to arrive in relays; also those birds

which do nest at the same time congregate together according to their species.

The droppings of various species of seafowl apparently do not have the same composition. This may be due to some organic difference, but more likely to a slightly different diet, perhaps at different seasons, for the variations in the droppings of the same kind of bird are no greater than the difference of composition between birds of different kinds. The late Mr. W. A. Dixon,[3] who spent some years on Malden Island, gives the following analysis of recent guano made by terns and frigate birds:

	Terns.		Frigate Birds.	
Water and organic matter	10.41	14.10	11.41	9.75
Calcium phosphate	72.49	79.21	84.34	81.91
Calcium carbonate	9.32	4.19	3.12	7.01
Calcium sulphate	5.82	2.17	0.79	0.98
Magnesium carbonate, alkalies, sand and loss	1.96	0.33	0.34	0.35
	100.00	100.00	100.00	100.00

ORIGIN OF THE PHOSPHATE.

In rainless districts the phosphorus is present as tri-calcic, di-calcic, ammonio-magnesic, and ammonia phosphate: only fermentation can take place under such circumstances. The oxalates and urates when in solution render the di-phosphates soluble. In rainy regions, the comparatively insoluble tri-calcic phosphate is left behind, while the soluble phosphates are leached out, react on the underlying coral rock and replace the CO_2 by P_2O_5. Mr. Dixon also remarks that the removal of the nitrogenous organic matter appears to be principally due to the action of the sun's heat, and not the rain, as is usually asserted, for though there is a considerable evolution of ammonia while the birds are on the ground, it disappears entirely during their absence of three months. Mr. Dixon found[4] the deeper layers of guano to be

[3] "The Guano and Other Phosphates Occurring on Malden Island" (*Trans. Roy. Soc. N. S. W.*, 1877, vol. XI., p. 176).

[4] "Notes on Huan Island Guano" (*Trans. Roy. Soc. N. S. W.*, 1878, vol. XII., p. 143).

invariably richer in calcium phosphate than those near the surface.

Carl Elschner [5] notes that the pinnacles on Nauru and Ocean island are dolomitic. Although this has no direct bearing on the deposit of phosphate, in the light of the information brought forward by the only deep bore hole put down on a coral island, viz., Funafuti in the Ellice Group, and the fact that this rock forms the bed on which the phosphate has been deposited, it may not be out of place to make a few remarks on the subject.

Dolomitization.—The cause of dolomitization is not clear, for in spite of numerous laboratory experiments, we are not sure that the natural conditions as to temperature, pressure, time, strength of solution and the presence of other salts which may assist or retard the natural reactions are correctly assumed; all we are certain about are the final results.

Elschner gives an analysis of coral sand from Nauru formed from recent coral as containing only 1.53 per cent. MgO; and recent coral from Ocean island as having 2.70 per cent. MgO. But analysis of pinnacles at Nauru gave from 35.70 per cent. $MgCO_3$ to 43.35 per cent. $MgCO_3$. From whence does this magnesia come? It is not in the original rock, and it is not in the bird droppings—or at least only a fraction of a per cent. —neither is it to be found to any extent in the phosphate rock. As it evidently came from outside, sea-water would seem to be the only source. L. Owen states: [6] "On most of the islands the underlying coral shows signs of partial dolomitization (43–45 per cent. of magnesium carbonate) the magnesium being chiefly derived from the guano." This percentage of magnesium carbonate is almost sufficient to make pure dolomite. He offers no proof that the magnesium was so derived, neither would such an origin account for the dolomite obtained from the Funafuti bore, referred to later on. Among his conclusions, Owen further re-

[5] "Corallogene Phosphat-Inseln Austral-Oceaniens und ihre Produkte" (Pvb. by Max Schmidt, Luebeck, 1913).

[6] "Notes on the Phosphate Deposits of Ocean Island with Remarks on the Phosphates of the Equatorial Belt of the Pacific Ocean," *Q. J. G. S.*, London, vol. LXXIX., for 1923, Pt. 1, No. 313, p. 1.

marks: "Before the deposition of the guano occurred, the reef was partly dolomitized."

Reef-forming organisms may be classed as those which form aragonite and those which form calcite. Among the former are the calcareous alga *Halimeda,* madreporian corals, the alcyonarian genus *Helipora,* the hydrocorallines, the majority of the mollusca, and the minute spicules of tunicates. Among the latter are calcareous algæ *Lithothamnion* and *Lithophyllum,* the foraminifera, the polyzoa, the echinodermata, and the spicules of alcyonaria.

Aragonite may be primary or secondary, likewise calcite, but dolomite is always secondary. Dr. C. G. Cullis [7] says that there is no evidence that magnesium carbonate exists in the bore cores of Funafuti otherwise than in combination with calcium carbonate. "The distribution of these three minerals in the boring is noteworthy. Aragonite is confined to the upper cores, the dolomite to the lower, while calcite, which is the constituent of the middle cores, is also found above and below, in association with aragonite on the one hand and dolomite on the other." Secondary calcite may be deposited on calcite or aragonite organisms, but secondary aragonite is only deposited on aragonite organisms and then only in those cases where the surface is clean and in cavities within the organism. It is well known that aragonite is less stable than calcite, into which it is frequently changed.

The distinction between aragonite and calcite was determined microscopically. The disappearance of aragonite commenced at about 100 feet, and it was practically all gone at 150 feet. The disappearance is due partly to the conversion of aragonite into calcite, and partly to solution. In recrystallizing, aragonite loses the organic texture originally characteristic of it. The secondary aragonite is more easily converted into calcite than the primary, and the secondary calcite is more readily converted into dolomite than the primary, which fact may partially account for dolo-

[7] "The Atoll of Funafuti. Borings into a Coral Reef and the Results. Being the Report of the Coral Reef Committee of the Royal Society." Published by the Royal Society of London, 1904, p. 353.

mitization in depth. The proportion of carbonate of magnesia in pure dolomite is 45.65 per cent.

The investigations at Funafuti were under the leadership of Professor (now Sir) Edgeworth David, who started the bore-hole with the best appliances available, but not being suitable for the depth required, the boring was continued the following year by Mr. A. E. Finckh. Numerous analyses of the cores were made by Mr. J. Hart-Smith, and quoted by Professor J. W. Judd in his contribution to the Royal Society's Report under the heading of "The Chemical Examination of the Materials from Funafuti." The following are some of these, and will give a good idea of the change in the contents of carbonate of magnesia with depth.

Depth.	%$MgCO_3$.	Depth.	%$MgCO_3$.	Depth.	%$MgCO_3$.
4	4.23	295	3.60	698	40.04
10	7.62	345	5.00	736	40.15
15	16.40	375	1.70	755	39.12
20	11.99	400	3.10	776	40.07
25	16.00	430	3.80	795	38.92
30	11.59	452	1.35	810	39.75
35	9.10	480	2.70	819	39.00
40	5.85	500	2.70	826	4.83
50	3.20	526	1.19	835	11.40
60	5.60	552	2.22	842	11.73
70	5.10	598	1.06	855	28.50
80	4.90	624	1.24	866	20.06
90	6.80	637	2.44	875	40.25
100	2.11	638.9	20.44	898	39.99
120	4.40	640	26.33	920	40.40
150	3.90	643	31.87	950	43.00
170	1.19	646	35.80	1,000	40.56
200	2.70	652	38.38	1,030	40.58
230	2.90	658	39.54	1,050	40.40
250	4.90	660	39.77	1,070	39.40
270	4.70	670	41.54	1,097	38.40
				1,114	41.05

It has been suggested that the increase of $MgCO_3$ in the upper portion of the bore hole was probably due to the leaching out of $CaCO_3$ while the less soluble $MgCO_3$ remained behind; and that the increase in $MgCO_3$ in the lower part was probably due to magnesium of the ocean replacing some of the calcium in the rock. No doubt both of these had a certain effect in the in-

creased proportion of $MgCO_3$, but if the upper portion of the rock owed the increase to the leaching out of $CaCO_3$, why were the cores between 40 and 637 feet so much lower? Was it because only the upper 35 feet were raised above the sea level, and had an opportunity of being affected by organic acids? Why do we find a sudden change in proportions between 826 and 842 feet? Was it due to a change in the physical nature of the rock? The rock was not all solid in this bore hole; in some places it was so rotten that a complete core could not be extracted. Mr. Albert Ellis, the New Zealand representative of the British Phosphate Commission, informs me that at Ocean Island, at a depth, the pinnacles are found to rest on an unstable layer of fragmentary coral, and that if great care is not exercised when removing the phosphate, the pinnacles will topple over.

Formation of the Phosphate.—A coral island may be raised a few feet above the level of the ocean owing to fragmentary reef material being cast up by storms.[8] Such islands are slightly higher at their edges than in the center, especially on the side exposed to the prevailing trade wind. These islands form ideal places for seafowl to breed. The coffee-colored guano on these islands, as well as on Surprise, is richer in the center of the island because it is not so contaminated with wind-blown sand. The deposit consists of about two feet of loose—so-called alluvial—guano, and another two feet of so-called cement guano, consisting of coral sand and shell grit partly changed into and cemented together with phosphate.

The next change is when a phosphate island is elevated by earth movements. This may be done in stages suddenly, or gradually, or the island may be alternately raised and submerged. An instance of the former is Walpole island, about a hundred miles south of New Caledonia. This island has an area of 296 acres, and is some 210 feet high. The island is bounded by precipitous cliffs, at the base of which is a fairly narrow shore reef or terrace covered with water at low tide. The cliffs show traces of at

[8] F. D. Power, "Coral Island Phosphates in the Making," *T. I. M. & M.*, 1919–20, vol. XXIX., p. 34.

least five former terraces. There is but one deposit of guano on the island, and that is on the top; it shows no signs of having been submerged since it was formed, any more than that of Surprise island, which it resembles. One remarkable thing about this guano is the high percentage of iron and alumina compared with that of Surprise.

Walpole ..... 6.72% ferric oxide, 12.57% alumina.
Surprise ..... 0.68% ferric oxide, 0.22% alumina.

Walpole shows no signs of vulcanism, though it is quite possible that it is built up on the edge of a submarine volcano. I was shown a piece of basalt picked up on the island, but it was evidently a former piece of ballast discharged with coal. Of course the ubiquitous pumice is there as on every sea coast of the Western Pacific. If the iron and alumina were due to the dust which spread all over the world in 1883 from the Krakatoa eruption, then we would expect to find as much if not more on Surprise island and that it would be confined to one stratum on Walpole. The problem of the origin of the iron and alumina has yet to be solved. The guano occurs between pinnacles varying from a few inches to 20 or 30 feet in height.

Nauru and Ocean Islands illustrate still another phase in phosphate formation, and since they are similar will be taken together. These islands have not only risen, but have also sunk since guano was deposited on them, and this more than once. The coral when raised sufficiently above high tide—which is normally about six feet—formed a breeding ground for seafowl. The latitude in which these islands occur is noted for its small rainfall, and at the present day, though vegetation is growing, it not infrequently happens that rain is falling round the island but not on it. This is because the air heated by the ground rises and drives the clouds away to sea. Although what rain there was acted as a solvent for the soluble phosphate, probably sea spray and dew were more active agents. The dead corals being cellular, the soluble phosphates would find their way into these and other cavities, take up the lime necessary to fix it as a tri-basic phosphate, gradually re-

place the coral structure and fill up some of the cavities. Fossil shells are always inside casts. Mr. V. Green of the Australian Fertilizers Proprietary Limited, Sydney, has in his possession two phosphatized eggs, 2 x 1⅜ inches, cemented to the ground where they were originally laid. To a smaller extent, tricalcic phosphate formed a thin mantle over the dolomite pinnacles which, with the gulleys between, were of course formed before the recent coral above referred to. There is a sharp line between the phosphate and carbonate which shows that the conversion was complete and not carried out in stages.

Some of the gulleys between the pinnacles were open; others were arched over, often with blow holes in the roof. The pinnacles themselves were carved out by wave action; their sides are nearly vertical, except at the top where they are inclined to be pointed (Fig. 2) which is probably due to the solvent action of

FIG. 2. Pinnacles on the shore reef not yet worn away.

acids and acid salts from the fresh guano, for the guano itself would otherwise protect the rock from ordinary atmospheric action.

Carbonate of lime, whether in the form of aragonite or calcite, being less tough and more soluble than the tribasic phosphate would be broken up and dissolved, setting free the phosphate which would collect in the gulleys together with some coral sand.[9] As the island sank, fresh coral growths would form round it, and

[9] F. Danvers Power, "Phosphate Deposits of Ocean and Pleasant Islands," *Trans. Aus. Inst. Min. Eng.*, vol X., 1905, p. 213.

so protect, to a certain extent, the debris collected between the pinnacles from being washed away. The island rose a second time, and conditions again became favorable for birds to visit the island in numbers and make fresh deposits of guano. The soluble phosphates not only acted as before but much which would have been lost under earlier conditions now found its way to the coral sand collected in the gulleys between the pinnacles and replaced the carbonate from without inward, forming concentric layers, made possible by the liquid occupying the interspaces; and these grains were in some instances cemented together with phosphate, forming an oölitic rock (Fig. 3). This can be well seen

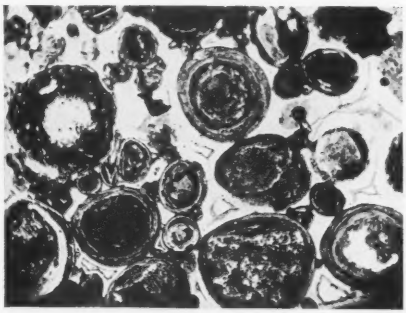


FIG. 3. Microscopic slide showing oölitic structure of the phosphate sandstone.

in microscopic slides. Fresh coral sand is more readily acted on than the dolomitic pinnacles, besides sand offers a larger surface for chemical action than larger pieces of rock. Naturally the phosphate-bearing liquid sank to the lower portion of the gulleys, and it is here one finds the phosphate sandstone, which is so hard it has to be blasted. The upper portion of the deposit is loose phosphate, commonly called "alluvial." As there are several connections between the gulleys and the ocean, and the sand is loose, the tidal water would draw out and push back the phosphatic liquid, causing a constant circulation, and in places an

agitation of the sand, which may account for the regular concentric layers to be seen round the nuclei (Fig. 4). The coral rock when freshly broken is milky white, but when weathered is

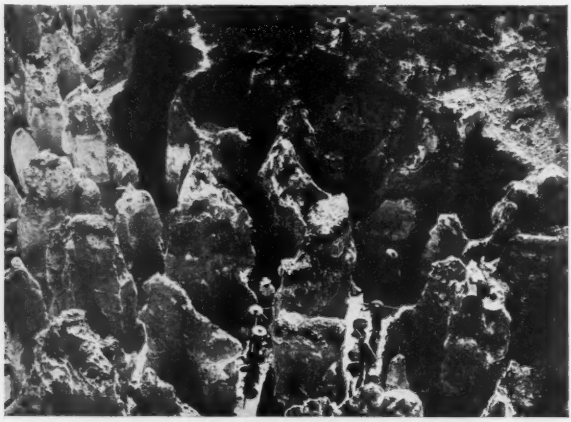


FIG. 4. Passages between pinnacles from which phosphate has been extracted. (Photo through courtesy of British Phosphate Commission.)

the usual limestone gray; whereas the phosphate rock is brownish when fresh, and white when weathered.

The island sank again; some of the phosphate sandstone became broken up and rolled about, forming boulders. Such boulders are found on the top of the islands, showing that the islands have risen yet again. This rising and sinking may have been repeated still more often, but there is no actual evidence of it. Though the oölitic structure and boulders of phosphate sandstone are a distinct help in interpreting what has taken place, it must not be thought that this, the "alluvial," and the mantle on the pinnacles, are the only forms in which the phosphate occurs, for in places are to be found layers of a sedimentary nature, evidently deposited on the floors of open spaces, also stalactites formed in caves, and various imitative forms.

Although the pinnacles are dolomitic, the phosphate rock only shows a trace of magnesia, which looks as if the dolomitization was brought about prior to the formation of the phosphate. Another interesting point about the phosphate of Nauru and Ocean island is that there is an excess of from 4 to 5 per cent. CaO over and above that necessary to form tribasic phosphate, carbonate of lime, and sulphate of lime. This has been noticed in the case of phosphates from other places and is attributed to the presence of lime in organic combination.

Owen does not agree with my interpretation of facts; he says: "The island (Ocean Island) shows no evidence of having suffered any extensive submergence since the deposit of guano. If submergence had occurred there would certainly have been left traces of coral beaches overlying the phosphate deposit. No such beaches have been observed. It may be argued that such beaches were converted into phosphate by solution leached from guano subsequently deposited. This may have happened, but I consider it very improbable." If the island has not been submerged and elevated at least two or three times as suggested above, how is one to account for the water-worn boulders of phosphate sandstone on the top of the islands? Yet in another place he writes: "The guano was deposited on a slowly rising reef, both depression and emergence appearing to have been regular and without sensible break." This does not seem to fit in with his previous remarks, or with his reference to the three tilted platforms which can be traced round the island, outside of which is an almost horizontal platform covered with recent beach material, and beyond this is the platform of marine erosion at sea level.

68½ PITT ST.,
SYDNEY, N. S. W.,
AUSTRALIA.

EDITORIAL

THE DANGER OF GENERALIZATIONS.

THAT it is dangerous to generalize or dogmatize in regard to mineral deposits will be the considered judgment of anyone who has followed the trend of ideas in economic geology during the past five-and-twenty years.

The controversies that have arisen and are still raging owing to the insistence by a number of geologists on the supergene origin of all chalcocite and certain silver minerals will at once suggest themselves, but I propose to deal more particularly with generalizations concerning the origin of epigenetic mineral deposits.

At the beginning of the period indicated, Van Hise, the last and greatest of the stalwarts of what J. E. Spurr has called the German school of geologists, had just made his really magnificent attempt to show that not only fissure veins but practically all types of epigenetic deposits are to be ascribed to the concentration by vadose waters in fissures, faults and other openings of metals and metallic compounds originally disseminated through the rocks forming the upper part of the earth's crust. This led inevitably to reaction in the form of a great rally by the magmatic-water geologists, and to the ultimate victory of that school. At the present day there is probably not a single serious student of economic geology who doubts that most mineral deposits are related genetically to intrusive igneous rocks.

It is, however, from the Zonal Theory of ore deposition, originated by J. E. Spurr, that the hypothesis has received its final vindication. That theory promises to be of the greatest practical assistance in the development of and search for mineral deposits, always provided that due caution and proper judgment are exercised in its application.

Concurrently with the development of these theories of ore deposition has been developed the idea of the genetic association of certain metals with particular types of igneous rock, or, to put it more scientifically, that in the differentiation of rock magmas

certain metals go with the basic, others with the intermediate, and yet others with the acid fractions. The principle is doubtless of fundamental importance, but here again the generalization has, in certain quarters, been carried too far. Thus the writer was taught that workable primary concentrations of the platinum metals are to be found only in ultrabasic rocks, and yet it was his privilege last year to be present at the opening up in a quartz lode, in the Waterberg district of the Transvaal, of what is probably the richest platinum ore ever found. The lode is in felsite and the minerals composing it are clearly the end differentiates of a persilicic magma or sub-magma.

Apropos of the question we are here discussing, it has always appeared to the writer that not sufficient account has been taken of the possible influence of the volatile constituents of the primary magmas on the ultimate distribution and concentration of the rarer metals that may be present in them. Take platinum for example. We know that that metal is generally precipitated in the magnesia-rich fraction of the magma, either in the native state or as sperrylite when arsenic is present. Assuming, however, that a platiniferous magma undergoing differentiation were rich in gaseous constituents capable of forming volatile compounds with platinum, then the probabilities are that the metal would be carried upward with the salic differentiates ready to escape into any fissure or opening in the roof of the magma chamber, there to deposit its load. Something of the sort must have happened in the case of the Waterberg deposit, but as yet we have no definite evidence as to the nature of the vehicle that transported the platinum. Judging, however, by the fact that in this and certain related occurrences the platinum is alloyed with palladium, the presence of that metal evidently favours the gaseous transfer of platinum.

It is questionable also whether the characteristic association of the deposits of certain metals, such as gold, with certain igneous rocks has any deeper significance than that the conditions during and immediately subsequent to the crystallization of such rocks were especially favourable to the concentration of the metals concerned.

The most recent generalizations on ore deposits are contained in J. E. Spurr's highly suggestive and stimulating work "The Ore Magmas." As was to be expected from its authorship, this is a valuable contribution to the science of mineral deposits, and yet the feeling appears to be general that in developing his well known views on the magmatic origin of ores Mr. Spurr has gone altogether too far. Some of his conclusions have already been challenged in these pages. It is proposed here merely to refer briefly to his conception of the formation of the types of deposits which he calls veindikes. These include as their typical representatives the ore-bearing pegmatites and pegmatitic quartz veins. They are assumed to have been formed by the injection into fissures and cracks of highly concentrated pasty ore solutions of magmatic origin, that ascended under their own force, and are capable of making room for themselves by pushing aside the walls of the fissures they invade. The manner of emplacement is thus regarded as being strictly analogous to the intrusion of igneous dikes and is described as ore injection.

This conception may be applicable to some of the deposits described by the author. It is certainly not applicable to many pegmatites and pegmatitic quartz veins that have been carefully studied. These, as Mr. Spurr himself emphasizes, bear evidence of having been formed in stages, evidently corresponding to definite temperature intervals in the cooling of the parent magmas. The early-formed quartz and feldspar or quartz, as the case may be, are usually barren of precious or valuable metals, which were only introduced subsequently to their consolidation through cracks and fractures opened up in them as a result of later movement. In some instances the ore minerals were deposited in such cracks, but in other instances it is clear that they have replaced the earlier formed minerals particle by particle.

In most of the tin-bearing pegmatites of the Central Transvaal there is not only unmistakable evidence that replacement has occurred, but that the introduction of minerals such as cassiterite, scheelite, and arsenopyrite was affected by solutions—evidently vaporous—that worked their way along microscopic and submicroscopic fractures, and were capable of penetrating the cleav-

ages of minerals so easily deformed as raven-mica, without in any way deforming them. In instances, such as those referred to, the magmatic solutions from which the barren silicates and quartz separated may have been injected in the manner suggested, but they were clearly not ore-bearing. On the other hand, the ore minerals were certainly not injected in a pasty condition. To designate the process of formation of such deposits as ore injection, in the sense in which Mr. Spurr uses that term, is thus misleading.

It is, however, when that author extends his hypothesis to embrace deposits other than the pegmatite or pegmatitic veins that the question arises whether he is not basing broad and far-reaching conclusions on inadequate data. Thus we are asked to believe that a well-known Canadian copper-zinc deposit, that of the Mandy Mine, which does not contain a single typical high temperature mineral and has been adequately explained by replacement and hydrothermal action, is due to the injection successively of a zincblende-chalcopyrite and of a chalcopyrite magma. Further, that the orebody of the Griffith Mine in Colorado, which has the earmarks of a vein formed by hydrothermal action under intermediate conditions of temperature and depth, is an intrusive veindike. Is not Mr. Spurr himself making an excursion into what he calls "the outer realm of unsubstantiated happenings" in concluding that the later brown carbonate of this deposit must have been introduced as fluid carbonates?

The truth is that the time is not yet for generalization such as we have been discussing. We know practically nothing of the laws governing the concentration and segregation of the rarer metals in cooling magmas; equally little of the nature of the magmatic solutions that give rise to mineral deposits, and of the physical chemistry of such complex solutions.

Until our ignorance is a little less profound let us keep speculation within legitimate bounds. That this course is wholly compatible with the real and rapid advancement of our science, has been demonstrated by the recent literature dealing with mineral deposits.

PERCY A. WAGNER.

DISCUSSION AND INFORMAL COMMUNICATIONS

OBSERVATIONS ON THE MINOR CONSTITUENTS OF PETROLEUM.[1]

Sir: Ramsey's note on petroleum in the Journal of the Society of Chemical Industry,[2] calling attention to the presence of nickel in many crude oils, has aroused considerable interest, a subject further discussed by DeGolyer and others in this *Journal.*[3] Ramsey suggests that nickel may have acted as a catalyst in the synthesis of paraffines from acetylene and hydrogen, and accordingly that its presence in petroleum strengthens the theory of the latter's inorganic origin in some cases. W. H. Thomas,[4] who has presented new data on the minor constituents of petroleum, argues against Ramsey's view with the claim that nickel is not found in the earth's crust in the metallic state.

Some analytical work is now being done in the Chemical Laboratory of the United States Geological Survey on petroleum cokes from various sources, the collection and study of which was the admirable suggestion of Prof. K. C. Heald. This work has already progressed far enough to render pertinent a few suggestions for the guidance of those who may be interested in the general problem of the minor constituents of petroleum.

The most striking feature about the petroleum cokes sent to the Survey for study is the wide variation in the percentage of ash. The usual ash is below one per cent. but one ran as high as 63.9 per cent. The writer has no information as to what these ashes would be on the basis of the original oils. The high-

[1] Published with the permission of the Director, U. S. Geological Survey.

[2] Ramsey, W., "Note on Petroleum," *J. Soc. Chem. Ind. Trans.*, 42, 287 (1923).

[3] DeGolyer, E., "The Occurrence of Vanadium and Nickel in Petroleum," ECON. GEOL., 19, 550 (1924).

[4] Thomas, W. H., "Petroleum Ash," *J. Inst. Petroleum Technologists*, 10, 216 (1924).

est ash, which included sand and fragments of rock, is of course unusual, but visible sand was present in the ashes of many of the cokes. It seems a logical step to assume that some fine silt might have been present in the crude oils, as well as the visible sand, and, in fact, even *colloidal material* of inorganic character. Therefore, although the presence of the usual constituents of rocks in the ashes of petroleum or petroleum cokes, may on careful study show some connection with the immediate source, or even the origin of the oil, such constituents should probably not be thought of as present in true chemical solution in the oil or as composing any part of its organic compounds. To draw significant conclusions from these constituents will be difficult if not impossible.

The case is somewhat similar with oil-field brines. These might well be examined for their rarer constituents, if possible, in order to compare the results with the minor constituents of petroleum. For the brines will be more or less entangled in the oils and the complete separation of the two is doubtless seldom accomplished before refining begins. The coke ashes are found to contain water-soluble salts, chiefly sulphates. Chlorides are generally absent. Most likely the chlorine forms volatile compounds during distillation and ignition, leaving the corresponding bases as sulphates formed from the sulphur-bearing hydrocarbons.

Wood, carbonaceous material, and petroleum are all known to reduce sulphates in the earth, which explains the frequent occurrence of pyrite, pyrrhotite, and other metallic sulphides in coal and the low proportion of sulphates in oil-field brines. It may be that this tendency is responsible for the occurrence of nickel in petroleum, to prove which it would only be necessary to show that the ratio of nickel to iron is not much different from that of nickeliferous pyrrhotites.

That the nickel may accompany petroleum as the volatile compound nickel carbonyl, $Ni(CO)_4$, is another suggestion that should receive further consideration.

The detection of nickel by dimethylglyoxime is a very delicate

test. One should therefore not overlook the ratio of such a minor constituent to other constituents in drawing conclusions as to its significance. Unfortunately, iron is doubtless introduced from piping. Traces of copper and zinc may come from brass fittings, or sieves, and so forth.

In the water-soluble salts of many ashes from petroleum cokes the writer finds strontium shown strongly by the spectroscope. The quantitative relations remain to be determined. Uranium has not so far been found. Phosphorus has not been found in the cokes tested for it, although Palmer [5] reports as much as 80 parts per million of phosphorus in oil from the Venture field, California.

In one ash containing over 6 per cent. V_2O_5 one half of the vanadium was found to be soluble in water, probably being present as sodium vanadate. The stage of oxidation of the vanadium in the coke, or in the oil, is not known. It is V_2O_5 in the ash, but must be as low as V_2O_4, and possibly V_2O_3, in the oil. It is suggestive in this connection to recall that vanadium in the stage of V_2O_3, is soluble in acid solutions but fairly easily precipitated in alkaline solutions, whereas in the stage of V_2O_5 its behavior is to a large extent just the opposite. This may have something to do with a tendency of vanadium to segregate in carbonaceous horizons. All indications point to the view that vanadium is probably carried in petroleum closely linked to sulphur.

The writer's determinations of petroleum coke ashes show that the water-soluble portion may range from 2 per cent. to 79 per cent. of the ash. As the data accumulate it will become possible to make comparisons between analyses of the water-soluble portions and those of oil-field brines.

The facts and observations here given incline the author to feel that there are rather more uncertainties than certainties regarding the significance of the minor constituents of petroleum, especially those found in the ashes of petroleum cokes.

[5] Palmer, Chase, "Phosphorus in California Petroleum," Econ. Geol., 17, 102 (1922).

Roger C. Wells.

U. S. Geological Survey,
Washington, D. C.

THE RATE OF SECONDARY ENRICHMENT BY ACID WATERS.

Sir: A report of laboratory experiments on enrichment, issued in 1913,[1] called attention to (1) the generally slow rate at which sulphide ores are attacked or replaced by dilute acid copper solutions; and (2) a rapid decrease in the rate at which certain minerals removed copper from cold dilute acid solutions. With moderate amounts of sulphide reagents and only roughly quantitative methods no action could be detected on any sulphide except alabandite in eighteen months. It did not seem likely such action could account for the enriched deposits known.

Zies, Allen, and Merwin reported in 1916[2] a series of experiments much more favorable to the idea that enrichment of copper ores might occur by the action of cold dilute acid copper solutions on common sulphides. Much of their work was done at temperatures of 50° to 200° C., but since reaction is fairly rapid they conclude that at ordinary temperatures the same reactions would probably occur, only more slowly.

The solutions on which the first report was based have now stood ten years. They were tested at the end of five years and have recently been given final tests by H. J. Conhaim, using several accurate methods. While the results show no new features they have the added accuracy of longer treatment, and warrant some calculations and a brief report. The order of activity of minerals agrees with that determined by Wells.[3]

Copper Added in 1 Liter Solution.	Minerals Added in Form of 40–200 Mesh Powder in Quantity Enough to React with All Copper.	Copper Precipitated in 10 Years at About 30° Centigrade.
.320 gram	Pyrite	None
.320 gram	Chalcopyrite	.006 gram
.320 gram	Sphalerite	.012 gram
.320 gram	Pyrrhotite	.070 gram
.320 gram	FeS_2 and ZnS	None
.320 gram	FeS_2 and $CuFeS_2$	None
.320 gram	Other mixtures	.019 to .045 gram

[1] Grout, F. F., "Behavior of Cold Acid Sulphate Solutions with Alkaline Extracts of Metallic Sulphides," ECON. GEOL., vol. 8, pp. 407–433, (1913).

[2] "Some Reactions Involved in Secondary Copper Sulphide Enrichment," ECON. GEOL., vol. 11, pp. 407–503, (1916).

[3] Emmons, W. H., "The Enrichment of Ore Deposits," U. S. Geol. Survey, Bull. 625, pp. 119–120, 1917.

Where Mr. Conhaim reports "none," there was no visible effect on the mineral surfaces and his method would easily detect the removal of .006 gram copper. It is certain that less than one per cent. of the copper reacted, as was expected when the work was started. In the cases of pyrite and sphalerite, the mineral was tested as well as the solution and the trace of copper was too small to be estimated by either the blue of ammonia or the iodide tests.

The significance of the results may perhaps be best shown by a rough calculation of the length of time needed for the reaction of a pyrite crystal to form chalcocite. Many enriched sulphide grains have a thickness of 1 mm. of chalcocite. The surface of sulphide exposed in the experiment was about 300 square centimeters. While no action whatever was detected, amounts smaller than .003 gram might have escaped our methods. If in ten years .003 gram copper as chalcocite replaced pyrite over an area of 300 square centimeters, it would form a layer less than 1/400,000 mm. thick. It would take at least 4,000,000 years to replace a layer 1 mm. thick; and probably many times as long as that because of the demonstrated retardation of the process as it proceeds.[4]

Similar calculations can be made for the other minerals and some approach to comparative estimates may be made from the work of Zies, Allen, and Merwin. The following may be taken as of the right order of magnitude, without being in any way a final exact estimate.

MINIMUM TIME REQUIRED TO REPLACE A THICKNESS OF 1 MM. OF PRIMARY SULPHIDE BY RICHER SULPHIDES UNDER THE ACTION OF FEEBLY ACID COPPER SULPHATE SOLUTIONS.

	At 200° C.	At 100° C.	At 35°–45° C.	At 25°–35° C.
Pyrite	20 years	13,000 years	1,000,000 years	4,000,000 years
Chalcopyrite	20 years		30,000 years	2,000,000 years
Sphalerite	50? years		10,000 years	1,000,000 years
Pyrrhotite	1 month ±	1 year	10,000 years	200,000 years

[4] Grout, F. F., *op. cit.*, p. 413.

Many local conditions might increase the time required: the presence of more acid and of iron sulphates retard the enrichment of pyrite [5] and must be almost universally present in the upper parts of enriched ores; the solutions in nature probably rarely become as strong as the 1 to 5 per cent. solutions used in experiments; and finally the formation of a replacing layer retards the action.

On the other side of the argument, no factor has been found to accelerate the enrichment except temperature, and if the temperature may be limited to a maximum of 45° C., the reactions in acid solution must be very slow.

The data seem to us to be enough basis for again calling attention to the suggestion that enrichment is likely to occur largely in the zone near the water table. Alkaline solutions from greater depths, which attack sulphides to a very considerable degree, here mix with the acid solutions from above, precipitating rich sulphides. In the zone of oscillating solutions enrichment might be very rapid in comparison with that in the higher zone where acid solutions act continuously, but at the slow rate shown in the table above.

FRANK F. GROUT AND H. J. CONHAIM.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

HOT SPRING WATER FROM CLIFTON, ARIZONA.

Sir: On a recent visit to the town of Clifton, I procured through the kindness of the mayor, a copy of an analysis made for the town of Clifton by Smith Emery Co. The spring in question comes out of basalt a few hundred feet from the Clifton railroad station and is at present developed by a shaft about 18 feet deep and a short cross-cut. It is uncomfortably hot, probably about 75° C., although I have no actual temperatures. It is mentioned by Lindgren in the Clifton Folio of the U. S. Geol. Surv. where he gives a partial analysis. The analysis given below is, however, complete. The spring is fairly large now and the

[5] Zies, Allen, and Merwin, *op. cit.*, pp. 443–4.

town of Clifton is endeavoring to develop more flow with a view to its possible exploitation as a medicinal water. Two or three miles above Clifton in the valley of the San Francisco river are some small adits which were abandoned on account of heat. It seems to me that any explanation of the Clifton Hot Spring will also explain the source of heat in the other locality. An examination of the analyses of the sedimentary rocks of the district as given in Lindgren's Professional Paper discloses no probable source for the large amount of NaCl. The location of the spring also indicates that the water is not connected with the sediments. The igneous rocks on the other hand, especially the quartz monzonite porphyry with which the ore bodies at Morenci are associated, contain appreciable amounts of this salt.

I believe therefore that this water is juvenile and is connected with one of the later igneous rocks of the district although there is not enough field evidence to definitely designate which.

CLIFTON HOT WELL.

Analysis by Smith Emery Co. for Town of Clifton. Recalculated to agree with form used in Clarke's Geo-Chemistry for purposes of comparison by R. S. Everit.

Per Cent. of Total Solids.	
Cl	59.14
SO_4	.60
CO_3	1.18
PO_4	Trace
Na	28.20
K	1.77
Li	.01
Ca	8.21
Mg	.21
Mn	.02
Al_2O_3 and Fe_2O_3	.03
SiO_2	.61

Salinity, 10,551.5 parts per million.

R. S. EVERIT.

BARRE, MASS.

ANGULAR INCLUSIONS AND REPLACEMENT DEPOSITS.

Sir: The interesting paper by Alan M. Bateman under the above title which appeared in ECONOMIC GEOLOGY (vol. 19, No. 6, Sept.–Oct., 1924, pp. 504–518) does not appear to the writer to be the only manner in which nuclei occurring in replacement ores may preserve their angularity. An additional factor in the production of angular nuclei by replacement processes presented itself to the writer as a result of the study of the progressive changes produced by the oxidation of a nickel-pyrrhotite ore. This nickel ore, outcropping at Dracut, Massachusetts, appears to have been extensively scoured by Pleistocene glaciation which removed preëxisting oxidation products. The least altered ore from the old mine workings contains pyrrhotite showing parallel bands of a substance harder than pyrrhotite, forming what might be described as a sort of grating structure. The mineral forming the grating, while perhaps not typical marcasite, represents a stage in the development of that mineral from pyrrhotite.[1] Pentlandite in the same specimen has not suffered alteration. Ore fragments which have been exposed to weathering on ore dumps for at least 40 years show a greater production of "marcasite" and in addition the alteration of pentlandite to "polydymite."[2] This "polydymite" is replaced by limonite as more advanced stages of the alteration are reached. Residual grains or nuclei of pentlandite remain in the limonite areas and are

[1] Gilbert, Geoffrey, "Oxidation and Enrichment at Ducktown, Tenn.," *Min. and Met.*, Preprint No. 1318–M, February 1924, p. 22. The specimen mentioned by Gilbert was collected by the present writer from the ore dump at the old Dracut mine.

[2] The exact nature of the "polydymite" remains in doubt. Lindgren and Davy (ECON. GEOL., vol. 19, No. 4, June–July 1924, pp. 315–319) suggest that material similar from Key West mine, Nevada is a new mineral for which the name "violarite" is proposed. Buddington (ECON. GEOL., vol. 19, No. 6, Sept.–Oct. 1924, pp. 529 and 541) makes the suggestion that these two minerals are bravoite.

marked by an angular outline. The factor which the writer believes to be important in the production of the angularity of these nuclei is the direction of chemical solution velocity. If the rate of the chemical solution is greater along one of two intersecting fractures, as a result of the orientation of the grain with reference to the direction of the fracture, the uneven rate of solution should prove an important factor in the development of angular outline in contrast to the rounded outline commonly developed, providing attack is uniform in every direction. The velocity of chemical solution is known to vary according to orientation and it is apparent that a factor of this nature cannot be ignored in any discussion of the origin of angular nuclei. This factor is unquestionably important in the consideration of structures on a microscopic scale.

The relation of grain size to angularity should throw light on the relative importance of chemical solution velocity in the production of angular nuclei on other than a microscopic scale. In the case of a fine grained rock the differential attack produced by variations in the orientation of the rock minerals should be rendered nearly inconspicuous as a result of the fine grain size of the individual minerals. The resulting outline of a fine grained rock fragment which has suffered replacement should, therefore, approach a smooth boundary. The consideration of the relative importance of this factor from a study of the influence of grain size is complicated by the following factors; Bowen's [3] conception of the reaction series involving the variation in reactivity between inclusions and magma. The concentrations of the substances effecting replacement in the replacing solution.

The corrosion of iron by etching solutions is instructive in the study of angular form in replacement at least on a microscopic scale. It is cited as an example of the control of internal structure over the manner in which corrosion will proceed. Howe [4]

[3] Bowen, N. L., "The Behavior of Inclusions in Igneous Magmas," *Jour. Geol.*, vol. 30, Supplement to No. 6, Aug.–Sept. 1922, pp. 513–570.

[4] Howe, H. M., "The Metallography of Steel and Cast Iron," McGraw-Hill, N. Y., 1916, p. 288.

describes the cubic pits developed by corrosion of iron, under the action of an etching solution, as remaining cubic through all stages of the etching process. He states that the natural inference that the sharp contours are due to a special resistance which they might have to corrosion is destroyed from the fact that during the growth of the pit its walls would pass through a series of concave shapes and would not be straight at any time. Howe explains the growth of these geometrical etching pits by a rapid removal of material as cubes. The internal structure of a substance constitutes an important factor in a consideration of the manner in which corrosion will take place.

It would appear to the writer that differences in chemical solution velocity should be considered and may be found to aid in the interpretation of angular nuclei.

ERNEST E. FAIRBANKS.

RENO, NEVADA.

REVIEWS

Magmatic Nickel Deposits of the Bushveld Complex in the Rustenburg District, Transvaal. By Dr. Percy A. Wagner. Memoir No. 21, Geological Survey, Pretoria, South Africa.

The lively discussion which has been going on for years as to the origin of the nickel-copper ores associated with norite and other basic rocks has mainly centered around the deposits of Norway and of Sudbury; but recently geologists working in South Africa have found similar ore deposits and have taken an important part in the controversy. The Insizwa ores were described some time ago by Goodchild as undoubtedly due to gravitational segregation; and Wagner, in the memoir mentioned above, gives an account of deposits connected with the Bushveld eruptive complex of the Transvaal and shows that they are due to magmatic segregation.

The Bushveld eruptives occur, however, on a much larger scale and with far more complication in their relationships than those of Sudbury and other nickel regions hitherto studied.

The nickel deposits are contained in a huge laccolithic sheet or lopolith of norite constituting the lower portion of the Bushveld Complex. The lopolith has a maximum thickness of 15,100 feet, but is differentiated into a number of related rock types, such as pyroxenic olivine norite, bronzitite, peridotite, anorthosite and anorthositic norite, the ore being associated mainly with the bronzitite. The ores occur in the zone of maximum differentiation in the lower part of the lopolith and Wagner accounts for this differentiation by the presence of abnormal amounts of sulphur in this part of the magma. There is, however, "no continuous ore zone such as exists at Insizwa and in some of the Sudbury Mines. The deposits take the form of completely isolated masses composed in part of disseminated sulphide or of 'mottled or poikilitic ore,' and in part of massive or solid sulphide ore. The disseminated ore preponderates."

The primary ore minerals are practically the same as at Sudbury, pyrrhotite, pentlandite and chalcopyrite being most common, though the first named mineral may be largely replaced by marcasite. Sperrylite is found and small amounts of the platinum metals as well as of gold and silver. Crystals of bronzite or of biotite occur even in the solid ore.

The disseminated sulphides are found throughout the enormous thickness of rocks belonging to the differentiated series; and the deposits "most probably owe their formation to heavy local showers of droplets

of gassy iron-nickel-copper matte that separated at a certain stage in its crystallization from the parent norite magma, and were aggregated under the influence of gravity." Wagner believes that there is "overwhelming proof that the sulphides are original constituents of the rocks in which they occur, and that replacement of silicates by sulphides has played a quite unimportant rôle."

The ore as sampled by Dr. Mellor averaged 3.3 per cent. Ni, and 0.59 per cent. Cu; which under favorable conditions of mining, smelting and refining should prove of a workable grade. It will be noticed that the proportion of copper to nickel is much smaller than in the Sudbury ores.

The Memoir is an admirable study of a very complicated bit of mining geology and should be read by everyone interested in the problem of the origin of nickel ores. A number of distinctly new ideas have been brought forward to remove difficulties in the explanation of the formation of ore bodies by magmatic segregation under the influence of gravity.

A. P. COLEMAN

ROYAL ONTARIO MUSEUM,
TORONTO, ONTARIO

The Story of Copper. By WATSON DAVIS. The Century Co., New York, 1924. 385 pp., 55 illustrations.

"The Story of Copper" is another of the numerous books of popular science which have recently found a wide audience among those interested in learning the historical and scientific background of the common phenomena of everyday life. It is a romantic and non-technical treatment of the subject, and endeavors to present the material in easily understood and readable language that is at the same time scientifically correct. The story starts with the imaginary discovery of copper by primitive man, and carries it through the many important uses of the present day. There are chapters on mineralogy, supply and distribution, mining and metallurgical methods, structure and chemistry of copper, the various alloys, and the countless uses of today. It is an interesting book for the lay reader, fully illustrated, with a bibliography for each chapter for those who may wish to study the subject more in detail.

A. A. BEECHER.

Field Book of Common Rocks and Minerals. FREDERIC BREWSTER LOOMIS. By G. P. Putnam's Sons, 1923.

In presenting this book the author has ventured into a pioneer field in that he is interested not in the student but in the amateur. The attempt is made to keep the book free from all except the most elementary of that terminology upon which the science of rocks and minerals is built.

Following an introductory chapter comes a short treatment of the forms

MAY 5 1925

and properties of minerals; this is concluded by a condensed analytical key based on the following physical properties in the order in which they are ranked: opacity, color, hardness, and streak. The greater part of the book is given over to descriptive mineralogy and petrology. The discussion of "each mineral or rock is introduced by a summary of its characters, then the features by which it may be distinguished from any other similar mineral (or rock) are given, after which its mode of origin" and its geographic occurrence are considered, the latter generally by states and countries in the case of the ore minerals but by more exact localities in the case of the silicates and rocks.

The book is profusely illustrated by photographic plates of rocks and minerals that have been colored. From the standpoint of utilizing the illustrations for identification however, the majority of them are of little or no value. The colors of the minerals in many cases are erroneous and misleading. Besides the photographs the book contains a large number of crystal drawings in that part that deals with the mineralogy.

It is believed that the author in his attempt to simplify the subject has sacrificed clearness to brevity. Crystallography is given a prominent position in the description of minerals and yet it is doubtful if an amateur or even a more experienced student would be able to locate a mineral in one of the six systems from the brief and vague treatment which is allotted to them in the second chapter. The crystallographic axes, to which the chief importance is attached, are explained as "lines of force," and none of the type forms are named except the three simplest ones of the isometric system, although some of the forms are described verbally for some of the systems.

A number of rather careless mistakes have crept into the text at various points.

The chief value of the book lies in the general discussion given under each rock, mineral and metallic element. Not only the layman but also the student will find here much that is instructive and presented in a very entertaining manner.

E. T. McKNIGHT.

SCIENTIFIC NOTES AND NEWS

Roy R. Morse, who has been professor of geology for four years in the University of California, is now with the geological staff of the Shell Company of California.

James W. Neill, mining engineer of San Francisco, has returned from an examination of mines in Japan for the Great Matsukatas.

A. F. Melcher has resigned from the U. S. Geological Survey and has accepted a position with the Marland Refining Company.

J. B. Burnett, for three years in charge of the geological explorations of the Mexican Eagle Petroleum Company in southern Mexico, and recently appointed assistant Chief Geologist of the combined Eagle and Corona Geological Departments at Tampico, has resigned the latter position and has accepted that of the Chief Geologist for the Lago Petroleum Corporation of New York and Maracaibo, Venezuela.

O. E. Meinzer, of the U. S. Geological Survey, has been granted a short leave of absence for work in Cuba, in which his principal problems will relate to possible leakage from a proposed reservoir connected with a public utility system.

At the meeting held in Tampico on February 4 by the Geological Luncheon Club, there were present twenty-three members representing eleven different companies.

Gerald FitzGerald and W. R. Smith, of the U. S. Geological Survey, who are to conduct geologic and topographic surveys in the southwestern part of Naval Petroleum Reserve No. 4 this year, sailed from Seattle for Seward, Alaska, on February 28.

Marcus I. Goldman, Geologist of the U. S. Geological Survey, gave an informal address on March 21st to the members of the Department of Geology of the University of Cincinnati on "The Cap Rock of Salt Domes."

Douglas R. Semmes has returned from Bombay, India, where he has been making a petroleum reconnaissance of one of the native states.

W. S. Ayer, of the University of Toronto, has accepted a position on the staff of the Canadian Geological Survey, and will be engaged in stratigraphic work in Alberta during the coming season.

E. K. Soper, with the Sinclair Oil Company, who has been in Europe for the past eight months on professional business, has returned to New York.

MAY 5 1925

H. A. Kee, formerly with the McIntyre Porcupine Mines, has been appointed consulting engineer for the Porcupine Davidson Gold Mines.

John G. Barry, formerly Chief Geologist of the American Smelting & Refining Co., working in Mexico and Chile, has opened an office as Consulting Mining Geologist and Engineer in El Paso, Tex.

C. H. Dane has left Washington for the oil fields of northern Louisiana, where he will be engaged in geologic work for the U. S. Geological Survey.

On March 13th and 14th a conference of Lake Superior geologists was held at the University of Wisconsin, at the invitation of Professor C. K. Leith, particularly to discuss problems of correlation in the Lake Superior region. In addition to the members of the Department of Geology, there were present at this conference geologists representing the Wisconsin Geological and Natural History Survey, Minnesota Geological Survey, Geological Survey of Canada, and a number of the iron and copper mining companies in the Lake Superior region.

Walter Douglas and T. A. Rickard have gone to Africa to examine copper properties.

W. A. Parks, professor of geology at the University of Toronto, is to succeed the late Dr. Willet G. Miller as president of the Geology Section of the British Association for the Advancement of Science.

J. A. Burgess, San Francisco mining engineer, has recently returned from making a mine examination in Venezuela.

Philip D. Wilson resigned from his position as Chief Geologist for the Calumet & Arizona Mining Co., and is now connected with the American Metal Co.

C. Lorimer Colburn has resigned his position as Assistant Chief Mining Engineer of the U. S. Bureau of Mines, and will be located at Cripple Creek, Col.

W. M. Davis, of the faculty of Harvard University has recently been studying fault lines in California in the neighborhood of Beaumont, Hemet and San Jacinto.

William McInnes, Director of Victoria Memorial Museum and Editor-in-Chief of the Department of Mines, Geological Survey, Ottawa, Canada, died on March 10th.

The Society of Economic Geologists is to hold its annual technical meeting Friday and Saturday, May 22d and 23d, 1925. The technical session will be held at Schermerhorn Hall, Columbia University, New York City, at 10 A. M. and 2 P. M. May 22d. That evening the members will leave for Lebanon, Pa., and Saturday, May 23d, will be spent in inspection of the Cornwall Ore Banks.